ENERGY CONSERVATION
IN
DRYING AND EVAPORATION

Part – 1 — Drying
Part – 2 — Evaporation

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PART –1

ENERGY CONSERVATION IN DRYING

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1.0 GENERAL

Driers are extremely used in — food processing chemicals, textiles, paper, cement, ceramics, timber and other process industries Drying involves the removal of a solvent or a dispersant to produce a solid product. Most drying operations are concerned with removal of water. Usually drying is the final step in a series of operations and the product from dryer is often ready for final packaging

Drying is an energy intensive operation, but the potential for energy savings available is not much understood or appreciated.

2.0 PROCESS DESCRIPTION

Mainly, two broad types are used

2.1 CONVECTION DRIERS

Also called as direct driers, because the evaporating medium, usually air or hot gas, makes contact with the material being dried and moisture is carried away in the air system Eg Drying rooms, spray driers, pneumatic driers, tunnel driers, etc

2.2 CONTACT OR CONDUCTION DRIERS

Sometimes called indirect driers. Here drying takes place by heat flow through a metal wall or platen roller on which the wet material rests eg continuous sheet driers such as paper machine cylinders or platen driers.

While in convection driers the air can be indirectly heated by steam ,hot water or heat transfer coil or even directly by hot gas from a furnace, depending on process requirement, in the contact driers the heating is indirect mostly by fluids such as — steam , hot water or heat transfer oils.

3.0 CONCEPTS OF DRYING

3.1 DRYING THEORY

Drying involves two fundamental and simultaneous processes —

— heat is transferred to evaporate liquid

— mass is transferred as a liquid or vapour within the solid as a vapour from its surface

Drying requires initial warming up, and a constant evaporation rate thereafter The evaporation rate is controlled by the rate of heat transfer at the evaporating surface

The rate at which the material dries is dependent on many factors

EXTERNAL

The drying — air temperature, humidity, velocity, turbulence, the material surface area and thickness or particle size

INTERNAL

The nature of material itself, which affect the migration of moisture to their surface by diffusion, capillary flow and flow due to gradients caused by gravity, by shrinkage or by internal vaporisation

While the external factors could be monitored, the internal influences are fundamental and cannot be controlled.

Generally, the limiting factors on drying rate are

— the rate at which the surface water can diffuse through the static air film at the material surface into the drying air-stream, and

— the maximum moisture gradient through the material which can be tolerated without damaging the material or restricting moisture flow by hardening or shrinking the surface layers

Typical drying characteristics curves and standard terminology in drying operations are given in Exhibit 1 and 2 respectively

3.2 DRYING CALCULATIONS

In order to carry out any specific calculations on air drying problems, it is necessary to have a knowledge of the properties of air and water vapour mixtures over the relevant temperature range

The relationship between most of these properties can be expressed in graphical form by a psychrometric chart as shown in exhibit 3 The following properties of air can be referred and are explained in exhibit 4

i) Dry bulb temperature

ii) Wet bulb temperature

iii) Moisture content

iv) Percentage saturation

v) Humid heat

vi) Humid volume

vii) Dew point

3.3. EQUILIBRIUM MOISTURE CONTENT (EMC)

EMC, is the limiting moisture to which a given material can be dried under specific conditions of air temperature and humidity It is therefore wasteful in energy to dry any product which is to be stored or used in contact with

atmosphere below this equilibrium moisture content.

The approximate equilibrium moisture contents of a few typical materials at 24°C and different humidity are given in exhibit — 5.

3.4 THERMAL EFFICIENCY OF DRYERS

In general it can be defined as the ratio of the amount of heat utilised for actual drying to the total heat supplied. It may be expressed in % basis or in kgs of steam required per kg of water evaporated.

Thermal efficiency is a function of drying air conditions, final moisture content, material to be dried and the type of dryer. Approximate thermal efficiencies for different types of dryers are given below

Sl No	Dryer Type	Thermal efficiency in % or Kg of steam/kg of water evaporated
1	Tunnel Dryer	0 9 — 1 1
2	Vacuum shelf dryers	60 — 80%
3	Double truck dryers	20 — 50%
4.	Rotary driers	
	a) Direct heated	55 — 75%
	b) Steam heated air	30 — 35%
5.	Spray dryers	About 65%

4.0 HOW TO GO ABOUT ENERGY AUDIT IN DRYERS

Sequential steps followed in an energy audit are enumerated below

4.1 Aim

The main aim of energy audit in any drier/equipment is to assess the present level of its thermal efficiency, locate areas of energy wastage and to suggest practical solutions such as waste heat recovery, air recirculation etc , to improve the overall performance

4.2 Data Collection

Energy audit starts by collecting the data such as type of dryer, fuel used, dryer configuration, product specification etc., which are helpful in understanding the total system.

4.3 Visual Inspection

The objective of visual plant inspection is to objectively evaluate the conditions of dryer and its associated equipment.

4.4. Details on Operation and Control of Dryer

To know exactly how dryers are being operated , the following points have to be analysed

* Actual operating conditions
* Desirable or designed conditions
* Production rates, quality, temperatures etc ,
* Cycle times
* Control systems
* Instrumentation
* Maintenance procedures
* Any special problem related to drying

4.5 Parameters to be measured

Generally, the minimum data to be taken in order to calculate the performance of a dryer are

1 Inlet and outlet moisture contents

2 Inlet and outlet gas temperature

3 Inlet and outlet material temperatures

4 Feed rate

5 Gas rate

6 Inlet and outlet temperatures

7 Retention time

8 Fuel consumption

Wherever possible, moisture contents and temperature should be measured at various points within the dryer

4.6 Instruments used

Frequently used instruments are listed below -

Sl No	Type of Instruments	Parameter measured
1	Positive displacement meters or Rotameters	fuel flow rate
2	Steam flow meter	Steam flow rate
3	Anemometer	Air or gas velocity
4	Manometer	Differential pressure
5	Temperature indicator with Thermocouple	Temperature
6	Hygrometer	Wet bulb temperature (Humidity)
7	Contact hygrometer	Moisture content of material
8.	Draft gauage	Dryer draft
9	Infrared gun	High temperature
10	Power analyser	Blower motor electrical Parameters

4.7 Analysis and Recommendations

With the help of all measured values, it is possible to calculate the mass and energy balance on a dryer A typical energy balance sheet (without figures) is shown in exhibit 6 If the thermal efficiency is low, look into all details of energy consumption, locate energy wasting areas and explore the possibilities of improving it

Energy conservation recommendations include improving insulation, recirculation of exhuast air, heat recovery from exhaust stream, etc

5.0 FACTORS INFLUENCING ENERGY CONSUMPTION

Faster drying is promoted by

— high air inlet temperature

— low air exhaust temperature

— high exhaust air relative humidity

These conditions promote heat transfer from the air to the product and mass transfer of liquid from the product to the drying air.

6.0 ENERGY SAVING AREAS

6.1 Maximising the Air Inlet Temperature

By raising the inlet temperature to the maximum compatible with material characterisitics, the energy transported by each kg of air is maximised and the volume of air exhausted to atmosphere is minimised. The heat source for the drier should be considered as steam batteries are likely to supply air at above 175°C and for higher temperatures, supplementary heating using hot oil or direct firing may be necessary. This may add to the capital cost of the installation and the additional losses at the intermediate heatings stages may offset gains due to higher drier efficiencies (a suitable level of insulation should of course be used). Weight of water removal by air at different temperatures is given in exhibit— 9.

6.2 Lowering the Air Exhaust Temperature

The lower the exhaust temperature from the drier, the greater the energy transferred from the air to the product for drying. Care must be taken to ensure that condensation does not occur in the drier or in the outlet ducting and that the increase in relative humidity does not adversely influence the drying rate. In practice, relative humidities upto 80% are economically acceptable.

6.3 Minimising the Initial Moisture Content of Dryer Feed

The energy required for drying depends on the quantity of water to be removed. Mechanical dewatering of solids and maximising the concentration of solutions fed to a drier will minimise the amount of water to be removed in the drier. Energy savings aspects in this regard is discussed in case study — 1

6.4 Avoiding Overdyring

If the final moisture content of the product can be raised without impairing its qualities, the energy required for drying will be reduced for two reasons. The total quantity of moisture to be removed will be reduced and the drier will operate more efficiently as higher exhuast relative humidities will be possible.

6.5 Heat Recovery by Exhaust Recirculation

If a part of the exhuast air from the drier is fed to the inlet, the energy required to supply a given amount of drying air is reduced by the energy in the recycled exhaust air. Care must be taken to ensure that the moisture in the returned air does not adversely influence the drying rate, but at normal drier exhaust temperatures and moderate recycle fractions this is not usually a problem. The return of fines from the product may be a more serious cause for concern. Case study — 2 discusses in detail about the exhaust air recirculation and product over drying

6.6 Heat Recovery by Heat Exchanger

If the exhaust air from the drier is passed through a heat exchanger, a significant part of the energy in the exhaust stream can be transferred to the incoming drying air and so reduce the need for additional heating. If a large fraction of the energy in the exhaust is to be recovered, facilities must be provided for the removal of condensate on the exhaust side of the exchanger and it may be necessary to filter the dirty air to remove fines and avoid fouling of the exchanger. In order to increase the energy recovery further, it is possible to use a heat pump in place of a simple heat exchanger. Heat recovery from exhaust gas is suggested in case study — 3

6.7 Multistage Processing

If a drying operation involves processing a product over a very wide range of moisture contents, it may be possible to divide the process into two or more stages and by optimising each stage individually reduce the total energy requirement for the operation. Additional benefits such as improved quality control may also result from such changes.

6.8 Dryer Insulation

Heat losses from drier housing vary enormously ie., from 2% of the heat input in the case of large rotary driers to 30% in the case of poorly insulated batch or room driers If dryer surface temperatures are more, care should be taken to minimise it by proper insulation. Case study — 4 explains the energy savings in this regard.

7.0 MODERN DEVELOPMENTS IN DRYERS

Several developments have taken place in recent years in which new types of driers or aids to drying have been used predominently for improved energy efficiency.

7.1 Air Knife

The air principle is an aid to drying designed to reduce the amount of water to be removed from the material by subsequent conventional dryers

It operates by blowing excess water off the material before the material goes into the dryer Air is provided by centrifugal blowers which develop relatively low pressures upto 70 kPa but high air volumes. The air passes through an elongated iar chamber with a precision formed orifice which matches the profile of the material to be dried The orifice converting the pressure energy to kinetic energy and generates a blade of air of a thickness between 01. and 3.0 mm typically travelling at between 180-825 kph. The principle is shown diagramatically on exhibit 11 and 12. The air knife breaks the water away from the surface of the material, thereby removing all surface water prior to final drying Only relatively small amounts of surface moisture and the water absorbed in the material therefore have to be dryed in a conventional manner

The benefits of the air knife can be summarised as follows:

* Increased process line speed
* Deduced thermal energy required for evaporation
* Reduced surface water or chemical staining
* Reduce thermal plant size

The main disadvantages of the air knife are:

* Increased noise
* Not suitable for complex shaped products

7.2 Heat Pump Dehumidifiers

The heat pump dehumidifiers (Exhibit 13) condense the water vapour in air streams.

The sensible heat and the latent heat can then both be recovered to be used as low grade heat for other processes.

Heat pump dehumidifiers are used extensively in evaporating pools and in timber drying applications.

7.3 Infra Red Heating

Infra red heating in frequently used to boost drying in a hot air drier (Exhibit 14)

Infra red emitters can be electricaliy heated or gas fired depending upon the wavelength required for the application. The main application for infra red dryers is in the textile processing industries. In these situations the infrared-unit is located at the wet or entry and where quite a small unit can effect a considerble increase in output. When moisture contents are high, intensities up to 50 kW/m2 can be used.

7.4 Dielectric Heating

Many non-metalic or dielectric materials will heat up uniformly when subjected to high frequency electromagnetic fields As the direction of field changes, the polarisation of individual molecules reverses rapidly causing friction and hence heat. The higher the frequency, the greater the movement

Dielectric heating uses radio frequency bands centered on 13.56 MHz and 37 12 MHz and microwave bands on 896 MHz and 245 MHz

Materials differ in their reaction to Rf and microwave heating and water is 100 times more receptive than most natural and synthetic fibres. Dielectric heating is therefore an ideal medium for drying applications It is particularly useful for final drying processes when conventional heating techniques are by no means as efficient (Exhibit 15)

Dielectric heating is particularly useful in the drying aplications in the textile and food industries. It offers the following advantages.

* Heating only in the product
* Shortened process times
* Increased productivity
* Reductions on energy costs
* Space savings
* Cooler environment

7.5 Ultra Violet Drying

Ultra violet dryers are used for drying of finishing processes in industries such as the paper and printing industries where solvent drying is necessary

Conventional drying processes can be replaced by the new approach of ultra violet drying (Exhibit 16) This process uses ultra violet light on the product which produces a drying effect by photo-chemical action on suitable materials such as varnishes

8.0 PLANNED PROGRAMMES FOR ENERGY CONSERVATION

1 Examine every possible way of reducing the amount of water to be removed Critically review the process preceeding the drier to ensure that maximum extraction of water is done mechanically or to see if preceding process can be modified to produce a feed stock containing less water. This entails checking condition of squeeze rolls or nip vacuum boxes or filters, hydro or centrifugal extraction to ensure that performance is maintained also in the case of web or sheet materials to ensure that the moisture expression is uniform across the width.

2. Overdrying is quite common and expensive on energy, as the moisture content of the material in the dryer approaches the desirable final value drying rate is very low indeed. Although overdrying implies that more moisture is evaporated than need be, by far the greatest effect is a marked drop in poutlet. Sometimes, overdyring is caused by uneven moisture content at the inlet to the dryer or in batch dryers by poor air distribution internally.

3 With air dryers check that heater batteries are clean, (some dryers not all) are fitted with air filters but often these do not remove very fine material which can foul up heater batteries. Drying potential will be reduced becuase (a) inlet air temperature falls and (b) air velocity falls Air speed is very important particularly during constant rate period

4 Where dryers are fitted internal nozzles (common in fabric drying) ensure that nozzles ar regularly inspected and cleaned. Blockage causes lowering of air speed and sharp drop in drying rate and increased energy consumption.

5 Gauges for indicating air pressure are very useful for showing when blockage is taking place but note if the gauge is between the fan and heater inlet, fouling up of heaters or air inlets will usually cause the pressure to go up not down Remember that a fan produces its highest pressure against closed damper (or blocked heater)

6 Where air nozzles are used for drying whether internally or externally, considered extending nozzles nearer to the material being dried in order to increase velocities at the surface. In many old driers, nozzles can be over 15 cms for the material and much of jet velocity is lost before it strikes the sheet.

7. Dry plant should be operated at high load factor for maximum economy, standing losses with air driers are usually much higher than the contact driers (eg cylinder or platen) Check loading of continuous driers and where these are stopped during meal breaks, ascertain if steam and fans are left running measure is empty. Manual control valves and steam supply should be easily accessible to operator.

8 With steam heated driers check that steam trap is dried for the job and located close to the heaters battery If steam or air locking occurs the heater battery output is reduced and some may argue that if this reduce steam flow then it ensures economy. On the contrary, this reduces outlet air temperature and drying rate or output and that is definitely uneconomical On the discharge side of the trap a suitable valve vent to atmosphere is a quick, useful way of checking trap operation. Where pre-drying cyljdners are used before the main air drier, it is usually possible to utilise flush steam for heating these.

9 It has been known for many years that most materials, when hot allow for much better water removal by mechanical means (eg. press magle or filter) principally due to the better draining properties (lower viscosity) of hot water Thus the amount of moisture to be removed in drain can be considerably reduced. In pre-mangling of pressing of fabric, increase in material temperature from 20°C to 65°C can reduce the amount of water to be removed in the drier upto 20%

10 Always consider the possibility of direct firing with gas or oil for convection driers. High temperature driers, must of necessity use direct firing in order to obtain the temperature level, but even where temperatures are about 165°C, it may be difficult to contain flash steam losses and direct firing or aq combination of these with steam, or high temperature heat transfer fluid may well be an economic solution

11 On cylinder dirers steam pressure is often reduced from the H P line via a reducing valve with a relief on the L P line. Oversizing or hunting of the reducing valve often causes excessive blowing of steam at the relief valve.

12 Ensure that steam is dry at the machine inlet Wet steam simply cover-loads the drainage system. Preferably

take steam feeds from the upper side of the supply main.

13. Check the amount of air recirculation to acertain whether this is as great as it should be, inadvertent air leakage effectively reduces recirculation and lowers drying temperature. Check casings, doors and materials inlets to ensure air infiltration is minimised. Also, recirculation os often set constant even though material moisture content varies and this cannot be economical; finally in driers not fitted with recirculation certainly consider it. It may seen that putting humid air back into the drier would inhibit drying and to some extent this is true but usually the dryer temepratur is increased by recirculation which tends to offset this.

14 Some driers using combustion gases employ indirect heating via heat exchangers to ensure clean hot air to avoid product contamination and this is particularly true of oil or cold fired systems Critically review this and examine the possibility of natural gas which may well be accepted for direct firing.

15. It may seem that with direct fired driers no combustion losses involved since all combustion products pass into drier or oven; often considerable quantity of excess air are used to dilute the gas in order to obtain the requisite temperature and combustion arrangement can be crued On several driers, we have measured significant amounts of carbo manoxide, inicating incomplete combustion amounting in some cases to 3% heat losse. So enusre that combustion gas analysis is carried out to verify this Often over dash chiller of flame and poor mixture is responsible

16 On direct fired driers which are temperature controlled, burner fluctuations due to course control systems is not uncommon, check that this is not occuring On steam batteries, faulty or wrongly controlled valves can cause wild pressure/temperature swings, when a controlled valve closes or nearly closes the heater battery becomes a condenser in the true sense of the word and serious water logging and condensate hold - up occurs

17 As a general rule driers are poorly instrumented Control of exhaust gas saturation or humidity is important and yet moisture meters are the exception rather than the rule Simple instruments such as pressure or draught gauges and temperature gauges are extreamely useful for ensuring correct operation and revealing faults The performance of a drier cannot be determined simply by looking at it from a distance

18 With cylinder driers, effective draining of condensate is essential and on machines which run intermittently ensure that cylidners are run for a short time after processing to clear the system, similarly on start-up Leaking valves allow condenate to collect and excessive condensate in the cylinders can damage cylinder condensate buckets and so prevent condensate removal altogether, also water logging increass power consumption considerably.

19 Heat losses from dryer housing varies enormously ie from about 2% of the heat input in the case of large rotary driers to 30% in the case of poorly insulated batch or room dryers. Many old driers can be improved considerably by better insulation of the casings Low pressure drying cylinder ends can be insulated and can reduce consumption of a dryer by as much as 4 5%

20 In drying a great deal of energy is lost as latent heat in exhausted moisture and it is in the area of waste heat recovery that good potential energy savings ie even in efficient drying applications where the gases leave in a highly saturated condition, latent heat in the exhaust represents a source of re- usable energy. Amongst the recovery systems available are gas/air, air/air heat pipes, heat exchangers, fixed and rotary and spray condensers.

CASE STUDY 1

CONTROL ON INITIAL MOISTURE CONTENT OF DRYER FEED

INDUSTRY · Synthetic fibre

EQUIPMENT . Squeeze Rollers

FUNCTION

Wet synthetic fibres are fed to squeeze rollers to remove excess free moisture. Gap between two rollers is controlled by high pressure mechanism

FINDINGS

Gap between two rollers are not controlled properly Variations are too wide resulting increased average moisture content in the squeezed product, which is fed to dryer for further processing

Final product samples from dryers are analysed for moisture content but not for the input material. Even a slight variation in the input material moisture content, will consume more energy for drying

RECOMMENDATIONS

Effective control on squeeze roller operation

Moisture estimation of the squeezed product before feeding to dryer

DATA

Operating hrs/annum	=	7000 hrs
Throughput rate	=	2.3 Tonnes/hr (dry product)
Extra moisture to be evaporated due to this pressure Variation	=	0.02 Kgs of water/kg of dry product
Exit humid air temperature	=	110^{o}C
Heat required to evaporate moisture	=	615 K Cal/Kg of moisture
Steam enthalpy at 10.4 Kg	=	480 K.cal/kg
Extra steam requirement is	=	615 x 46/480 = 58 9 Kg of steam
Therefore steam cost (approximately)	=	Rs. 360/Ton
Oil cost	=	Rs. 5/lit

Energy saved per annum	=	29 6 K.lit of oil/year
Rupees saved per annum	=	1.48 lakhs
Cost of implementation	=	Marginal
Payback period	=	Small

CASE STUDY 2

EFFECTS OF OVERDRYING AND EXHAUST AIR RECIRCULATION

TYPE OF INDUSTRY : Paper

EQUIPMENT : Paper dryer

OPERATION

Paper is doped continuously and then dried by air that is blown through a steam heater. Some of the exhaust air is recirculated to mix with the fresh air at the heat inlet Schematic representation in provided in Exhibit—10

STUDY

1 Benefits of increasing the recirculation of exhaust air

2. Increasing the moisture content of paper upto its equilibrium level are best explained by this case study

DATA

Details	Present	Proposed
1 Initial moisture content from take off reel	6% dry wt	6% dry wt
2. Moisture content after dope bath	23 6% dry wt	23 8% dry wt
3. Moisture content after dryer	2 2% dry wt	5 8% dry wt
4 Throughput rate(dry paper)	360Kg/hr	360 Kg/hr
5 Fresh air intake	41%	17%
6. Recirculated exhaust air	59%	83%
7. Exhaust air moisture	0 0136 Kg/Kg dry air	0 0240 Kg/Kg dry air

CALCULATIONS

Details	Present	Proposed
1 Heat input		
Heat to circulating air from steam	100%	100%
2. Heat output		
a) Heat used to evaporate moisture	10 9%	24 8%
b) Heat lost by exhaust air	59 9%	48 7%
c) Heat lost in heat content of paper	0 5%	2 0%

Details	Present	Proposed
d) Other losses	28.7%	24.5%
3. Steam consumed	863.6 Kg/hr	321.7 Kg/hr
4. Throughput rate	360 Kg/hr	360 Kg/hr
5 Water evaporated	77 04 Kg/Hr	64.8 Kg/hr
6 Thermal efficiency	10 9%	24.8%
7. Hours of operation/year	8400 hrs	8400 hrs
8. Fuel price/ton of steam	Rs 360/ton	Rs 360/Ton

Energy saved = 325 KL of oil/Year

Cost saved = Rs 16 3 Lakhs/Year

Cost of implementation = NIL

Pay back period = Immediate

CASE STUDY 3

HEAT RECOVERY FROM DRYER EXHAUST AIR

INDUSTRY : Food processing EQUIPMENT Spray dryer

FINDINGS : No heat recovery from hot exhaust air

DATA

Exit air temperature	=	105°C
Heat in exit air	=	7,00,000 K.Cal/Hr
Recoverable heat	=	80%
Preheated inlet air temperature	=	90°C

RECOMMENDATIONS

Spray dryer hot exhaust air can be utilised to preheat fresh air intake using heat pipes as finned tube heat exchanger. Cost of implementation and payback period have to be worked out:

Energy savings	=	150 KL of Oil/Year
Cost savings	=	Rs 8 — 9 lakhs/Year

CASE STUDY 4
DRYER INSULATION

INDUSTRY : Textile

EQUIPMENT : Tunnel dryer

OPERATION

Wet staple fibres are fed continuously from one end and dryed fibres (6% — 10% moisture) are delivered a other end.

FINDINGS

— Poor insulation

— Surface temperature was 70 — 80°C

— Heat loss through dryer surface and exhaust air given in exhibit 7.& 8.

DATA

Room temperature	=	35°C
Average dryer surface temperature	=	75°C
Dryer surface area	=	60 m2
Allowable dryer surface temperature	=	50°C
Dryer operation	=	7600 hrs/year
Effective heat lost through surfaces	=	280 watts/m2

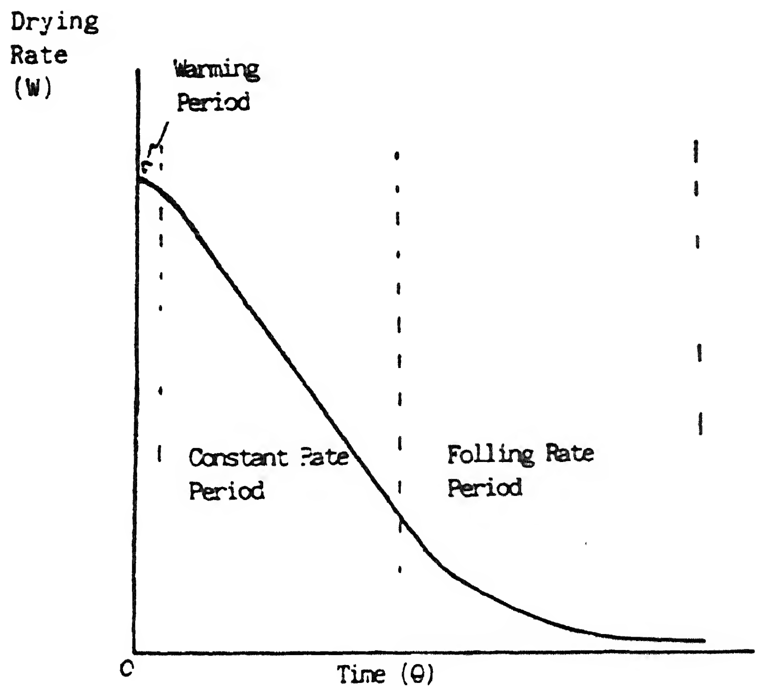
RECOMMENDATIONS

Increase insulation thickness to get 40 — 50°C surface temperature

Energy savings	=	13.6 KL of oil/year
Cost savings	=	Rs. 68,000/Year
Cost of implementation	=	Rs.1,00,000
Payback period	=	1.5 Years

EXHIBIT. I

TYPICAL DRYING CHARACTERISTICS



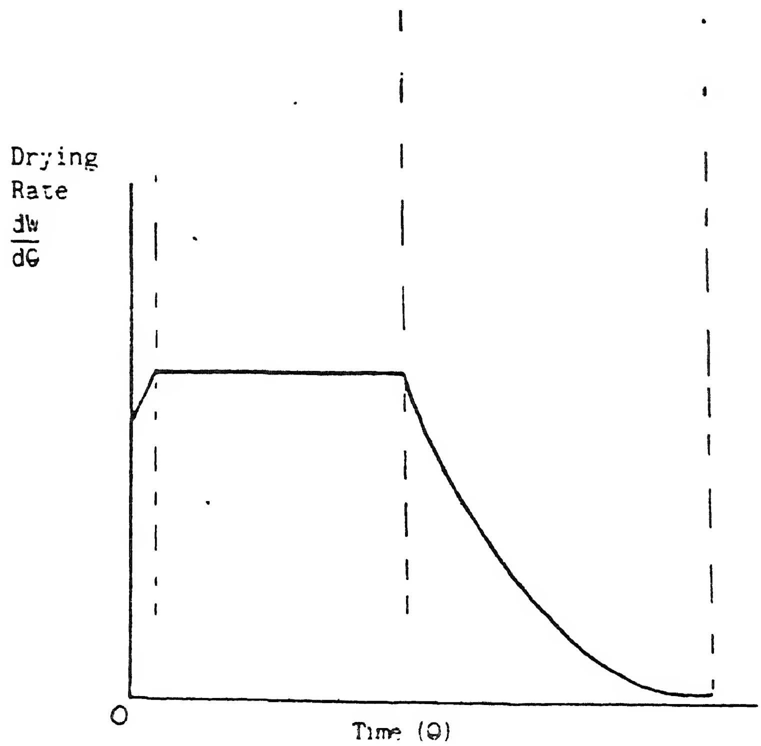


EXHIBIT 2

DRYER TERMINOLOGY — DEFINITIONS

1. *Bound Moisture*

In a solid is that liquid which exerts a vapour pressure less than that of the pure liquid at the given temperature. Liquid may become bound by retention in small capacities, fiber walls, etc.,

2. *Free Moisture Content*

Is that liquid which is removable at a given temperature and humidity. It may include bound and unbound moisture.

3. *Critical Moisture Content*

Is the average moisture content of when the constant rate period ends.

4. *Constant Rate Period*

Is that drying period during which the rate of water removal per unit of drying surface is constant.

5. *Falling Rate Period*

In a drying period during which the instantaneous drying rate continually decreases.

6. *Moisture Content*

Of a solid is usually expressed as moisture quantity per unit weight of the dry or wet solid.

7. *Dry Weight Basis*

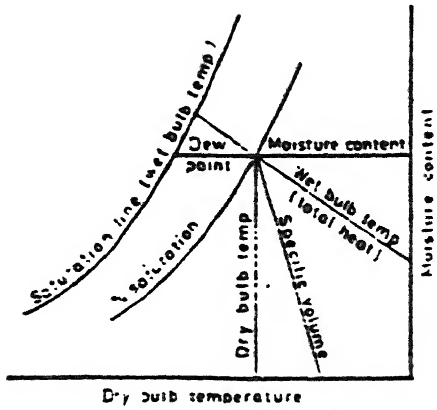
Express the moisture content of wet solid as kilograms of water per kilogram of bone dry solid.

8. *Hygroscopic Material*

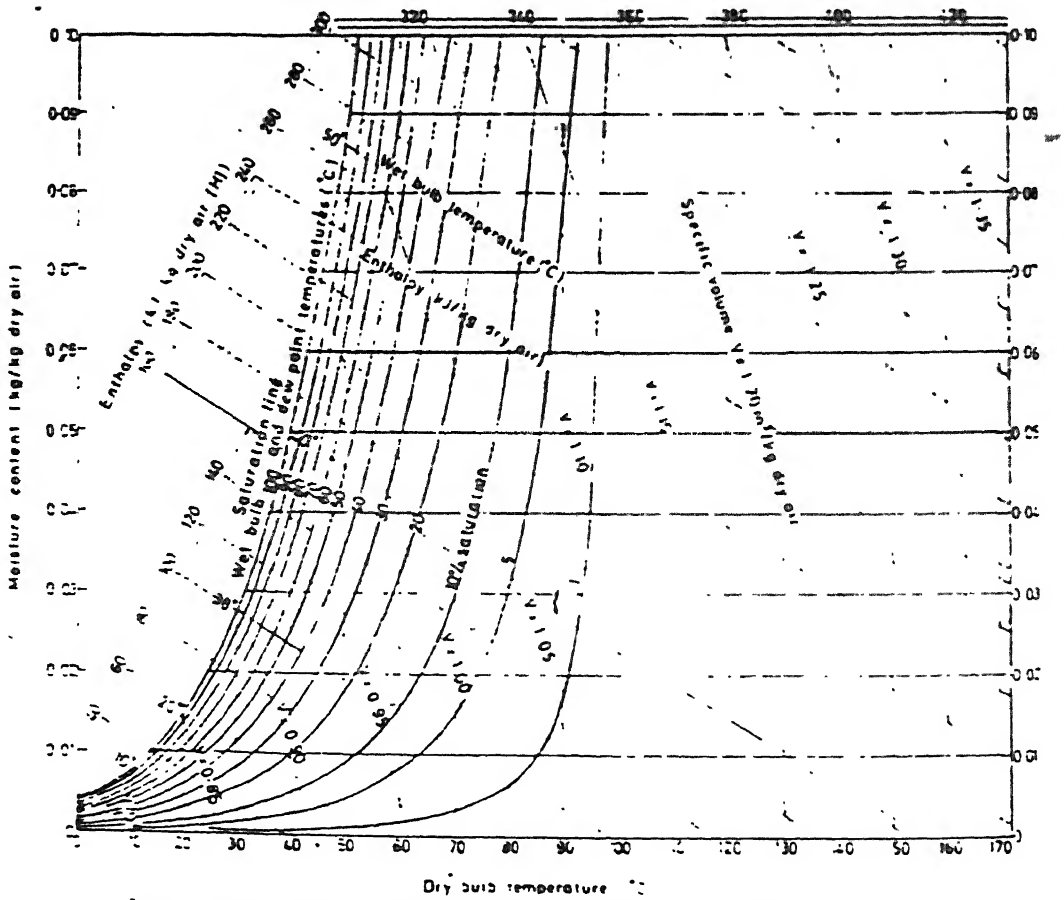
Is a material that may contain bound moisture.

EXHIBIT-3

PSYCHROMETRIC CHARTS (THE PRINCIPLES)



Psychrometric chart (principles)



Psychrometric chart (based on a barometric pressure of 1013.25 mbar)

EXHIBIT 4

AIR WATER VAPOUR MIXTURE — TERMINOLOGY

1. *Humidity*

Is the mass of vapour carried by a unit mass of vapour free gas (generally air)

2. *Relative Humidity*

Is defined as the ratio of the partial pressure of vapour to the vapour pressure of the liquid at the gas temperature. It is usally expressed on a % basis.

3. *Percentage Humidity*

Is the ratio of the actual humidity to the saturation humidity at the gas temperature, also expressed on a percentage basis.

4. *Humid Heat*

Is the Btu (heat) necessary to increase the temperature of one pound or one gram of gas, plus whatever vapour it may contain, by 1°F or 1°C.

5. *Humid Volume*

Is the total volume of a unit mass of vapour free gas plus whatever vapour it may contain, at 1 atm and the gas temperature.

6. *Dew Point*

Is the temperature to which a vapour gas mixture must be cooled (at constant humidity) to become saturated. The dew point of a saturated gas plant equals the gas temperature.

7. *Total Enthalpy*

Is the enthalpy of a unit mass of gas, plus whatever vapour it may contain.

EXHIBIT : 5

REGAIN OF HYGROSCOPIC MATERIALS
(Basis—Uniform temperature of 75°F. (24°C.))

	Material	Description	Regain on dry weight at indicated per cent relative humidities								
			10%	20%	30%	40%	50%	60%	70%	80%	90%
Natural Textile Fibres	Cotton	Sea island-roving	2·5	3·7	4·6	5·5	6·6	7·9	9·5	11·5	14·1
	Cotton	American cloth	2·6	3·7	4·4	5·2	5·9	6·8	8·1	10·0	14·3
	Cotton	Absorbent	4·8	9·0	12·5	15·7	18·5	20·8	22·8	24·9	25·8
	Wool.	Australian merino skein	4·7	7·0	8·9	10·8	12·8	14·9	17·2	19·9	23·4
	Silk	Raw chevennes skein	3·2	5·5	6·9	8·0	8·9	10·2	11·9	14·3	18·8
	Linen	Table cloth	1·9	2·9	3·6	4·3	5·1	6·1	7·0	8·4	10·2
	Linen	Dry spun yarn	3·6	5·4	6·5	7·3	8·1	8·9	9·8	11·2	13·8
	Jute	Average of several grades	3·1	5·2	6·9	8·5	10·2	12·2	14·4	17·1	20·2
	Hemp	Manila and sisal rope	2·7	4·7	6·0	7·2	8·5	9·9	11·6	13·6	15·7
Rayons	Viscose Nitrocellulose Cupramonium Cellulose	Average skein	4·0	5·7	6·8	7·9	9·2	10·8	12·4	14·2	16·0
	Acetate	Fibre	0·8	1·1	1·4	1·9	2·4	3·0	3·6	4·3	5·3
Paper	M.F. Newsprint	Wood pulp, 24% ash	2·1	3·2	4·0	4·7	5·3	6·1	7 2	8·7	10·6
	H.M.F. Writing	Wood pulp, 3% ash	3·0	4·2	5·2	6·2	7·2	8·3	9·9	11·9	14·2
	White Bond	Rag, 1% ash	2·4	3·7	4·7	5·5	6·5	7·5	8·8	10·8	13·2
	Comm. Ledger	75% rag, 1 . ash	3·2	4·2	5·0	5·6	6·2	6·9	8·1	10·3	13·9
	Kraft Wrapping	Coniferous	3·2	4·6	5·7	6·6	7·6	8·9	10·5	12·6	14·9
Various Organic Materials	Leather	Sole oak-tanned	5·0	8·5	11·2	13·6	16·0	18·3	20 6	20·4	29·2
	Catgut	Racquet strings	4 6	7·2	8·6	10·2	12·0	14 3	17 3	19·8	21 7
	Glue	Hide	3·4	4·8	5·8	6·6	7·6	9·0	10 7	11·8	12·5
	Rubber	Solid tyre	0·11	0·21	0·32	0·44	0·54	0·66	0·76	0·88	0·9
	Wood	Timber (average)	3·0	4·4	5·9	7·6	9 3	11 3	14 0	17 5	22·0
	Soap	White	1·9	3 8	5·7	7·6	10 0	12 9	16 1	19·8	23·8
	Tobacco	Cigarette	5 4	8 6	11 0	13 3	16 0	19 5	25 0	33 5	50 0
Foodstuffs	White		0 5	1 7	3 1	4 5	6 2	8 5	11 1	14 5	19 0
	Crackers		2 1	2·8	3 3	3·9	5 0	6 5	8 3	10 9	14·9
	Macaroni		5 1	7·4	8 8	10 2	11 7	13 7	16 2	19 0	22 1
	Flour		2 6	4 1	5·3	6 5	8 0	9 9	12 4	15 4	19 1
	Starch		2 2	3 8	5·2	6 4	7 4	8 3	9 2	10 6	12 7
	Gelatine		0 7	1 6	2 8	3 8	4 9	6 1	7 6	9 3	11 4
Various Inorganic Materials	Asbestos fibre	Finely divided	0 16	0 24	0 32	0 32	0 41	0 51	0 62	0 73	0 84
	Silica gel		5 7	9 8	12 7	15 2	17 2	18 8	20 2	21 5	22 6
	Domestic coke		0 20	0 40	0·61	0 81	1 03	1 24	1 46	1 67	1 86
	Activated charcoal	Steam activated	7 1	14 3	22 8	26 2	28·3	29 2	30 0	31 1	32 7
	Sulphuric Acid	H_2SO_4	33 0	41 0	47 5	52 5	57 0	61 5	67 0	73 5	82 5

Note —Regain is the equilibrium moisture content of a hygroscopic material in contact with moist air. It is expressed as moisture content per cent of dry weight of the material

Thus 100 lb. (or kg.) dry weight of wool will weigh 108·9 lb. (or kg.) when in equilibrium with air of 30 per cent relative humidity and 119 9 lb. (or kg) when in equilibrium with air at 80 per cent relative humidity

EXHIBIT 6.

ENERGY BALANCE FOR DRYER

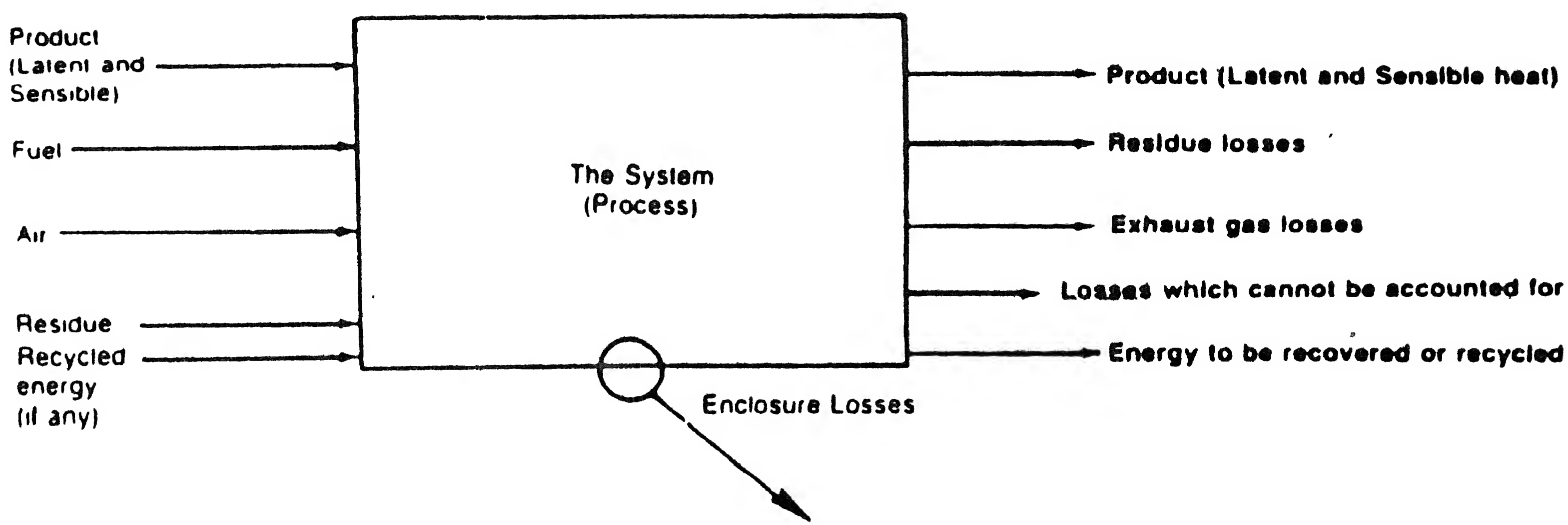


EXHIBIT 7

ENERGY LOSS IN DRYER EXHAUST AIR

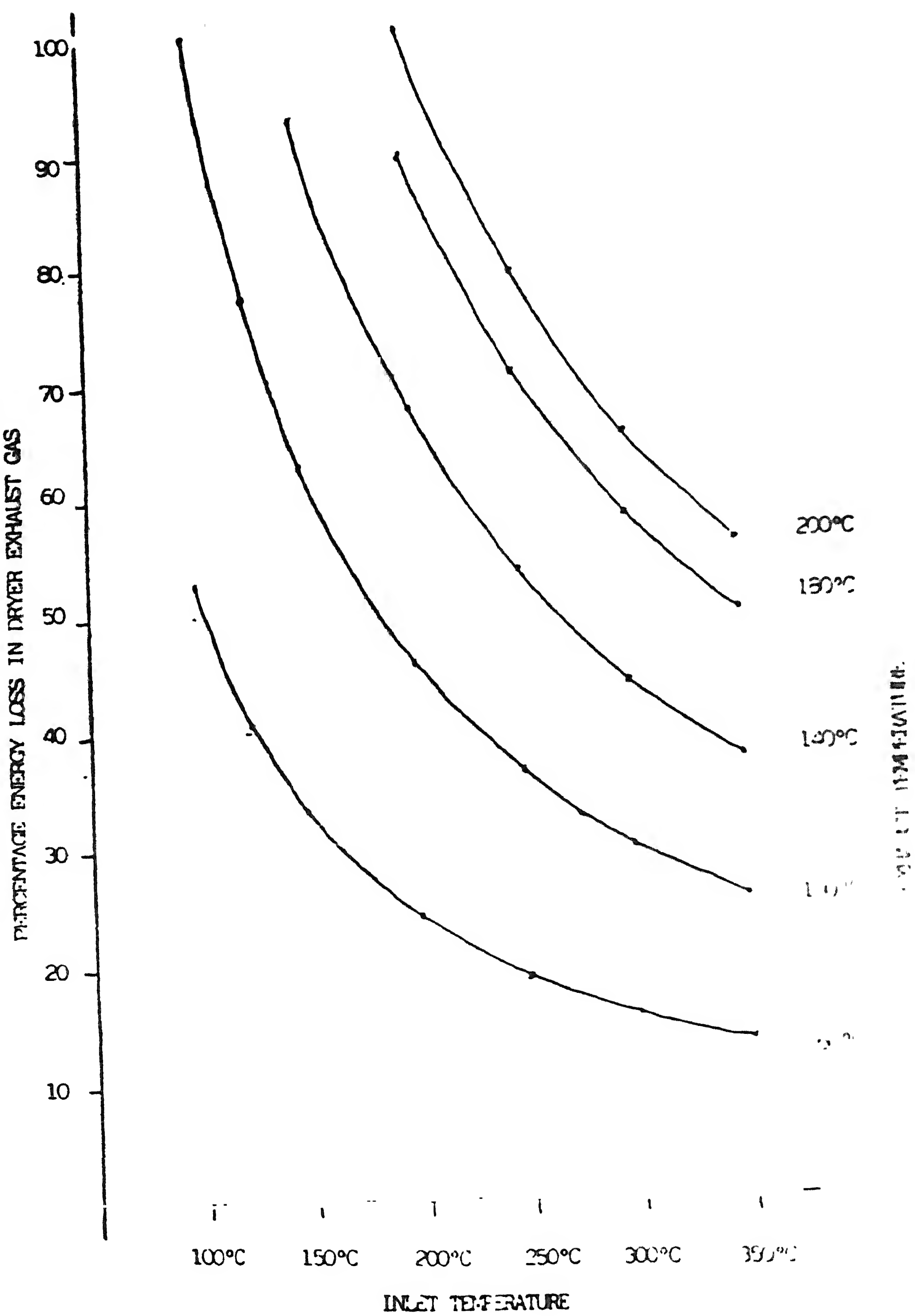


EXHIBIT - 8

ENERGY LOSS FROM DRYER WALLS VERSUS OUTSIDE WALL TEMPERATURE

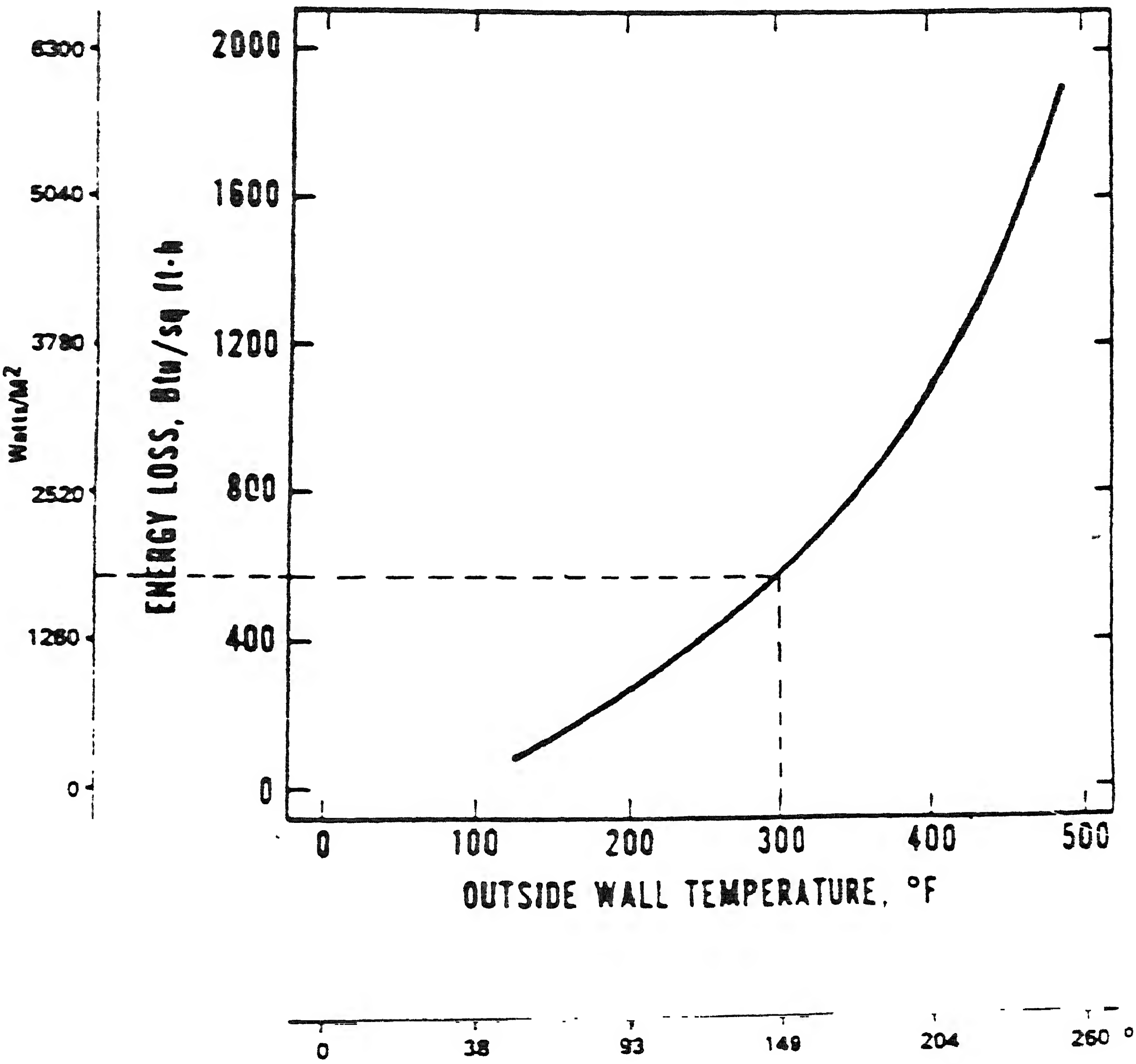
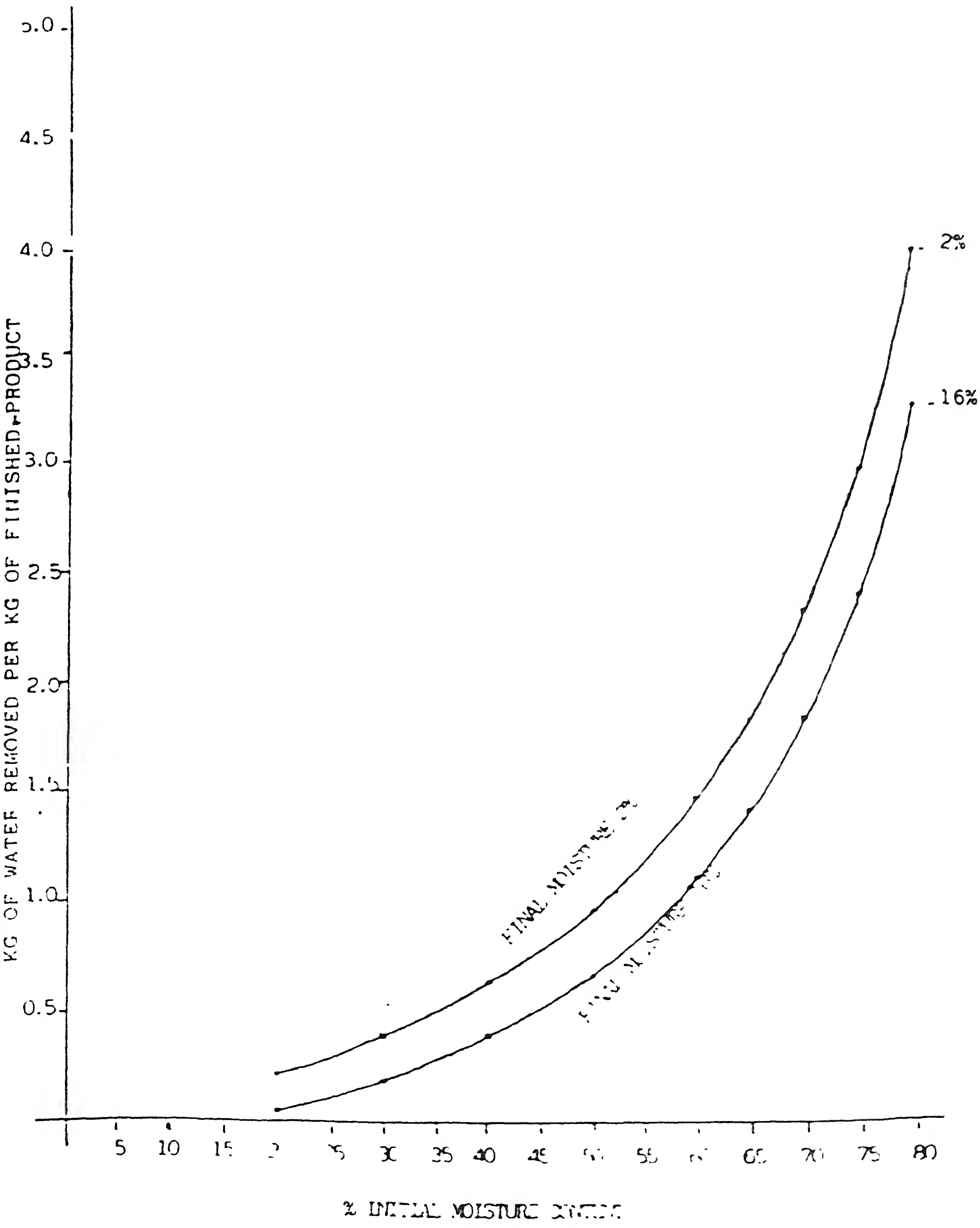


EXHIBIT 9

WEIGHT OF WATER REMOVED BY DRYING



EXAMPLE PAPER DRYER

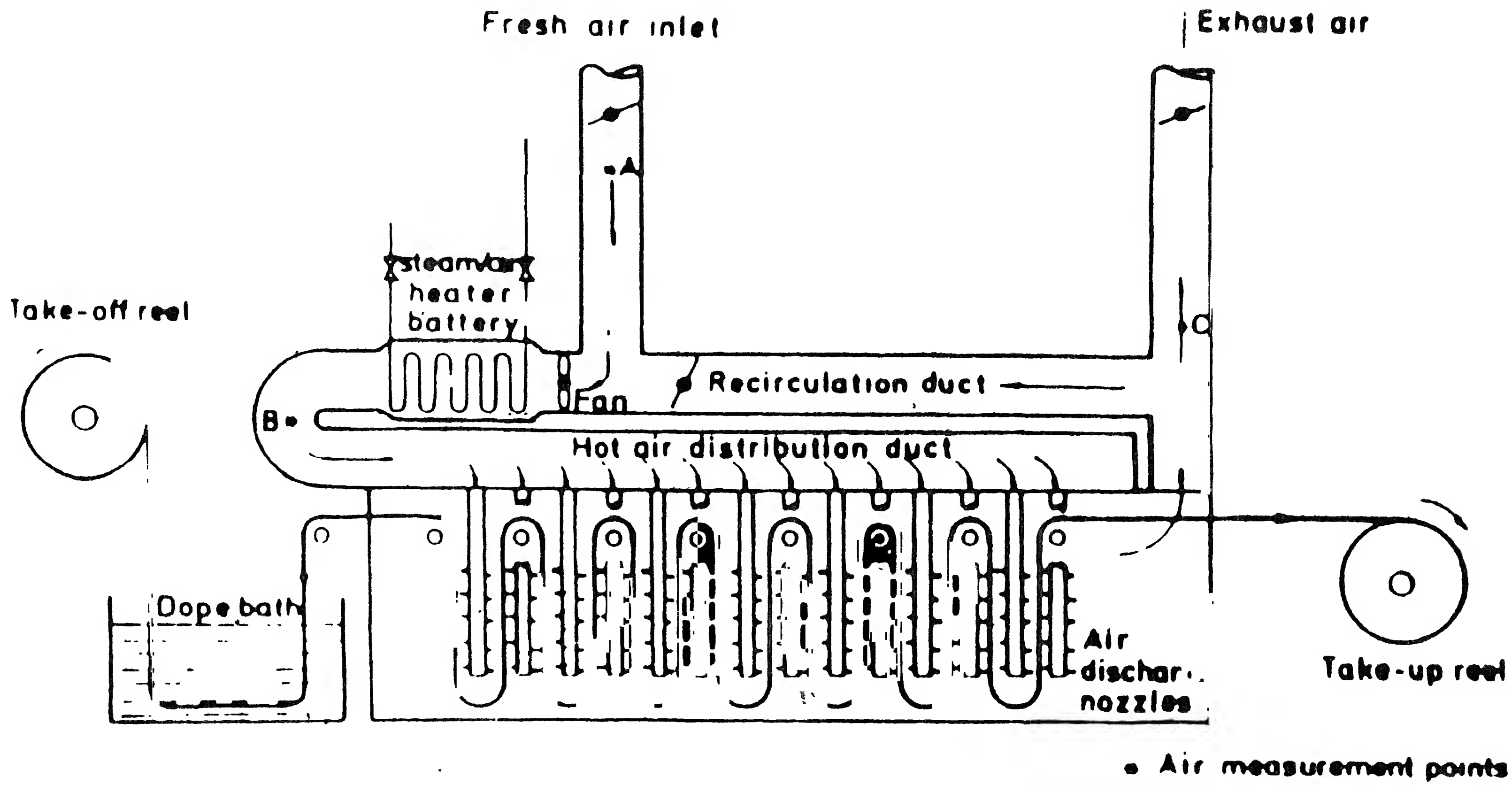
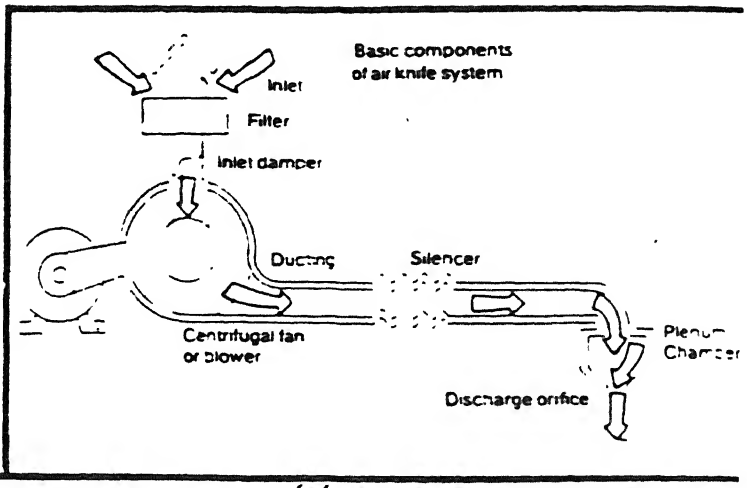
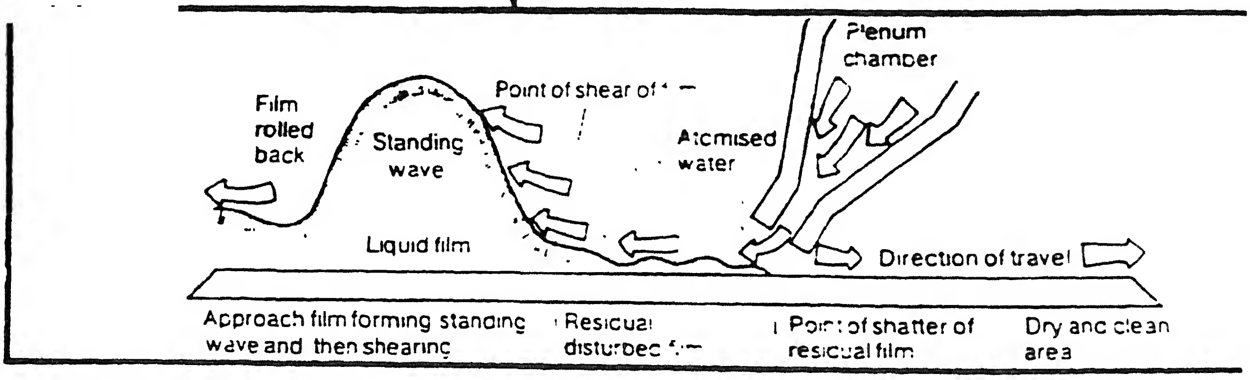
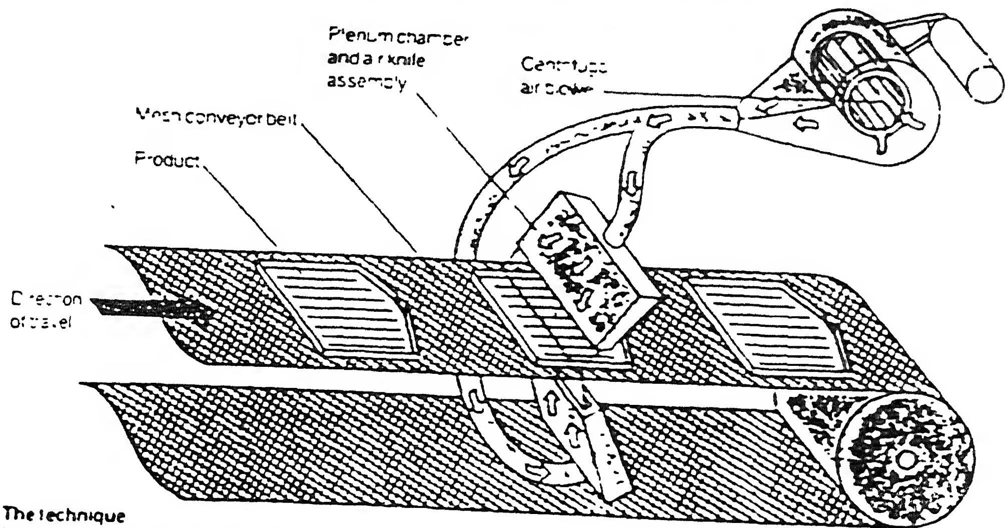


EXHIBIT 11

BASIC COMPONENTS OF AIR KNIFE SYSTEM



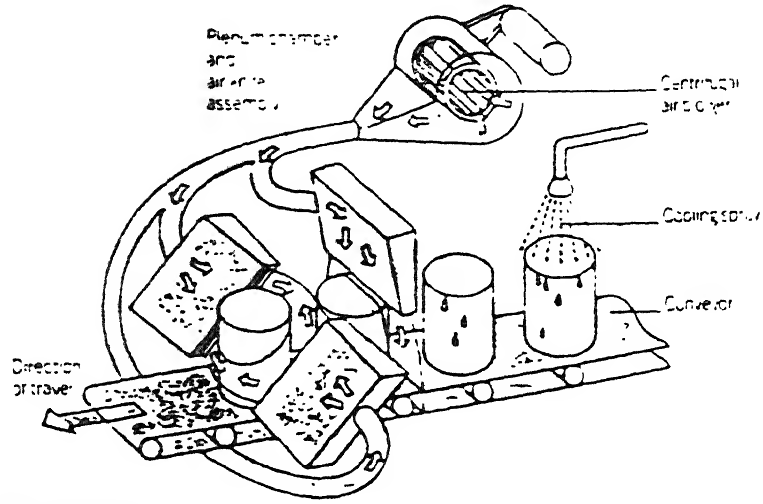




The technique
The air knife uses high velocity low pressure air to blow water off the surface of a wide range of products.

EXHIBIT-12

TECHNIQUE : AIR KNIFE SYSTEM

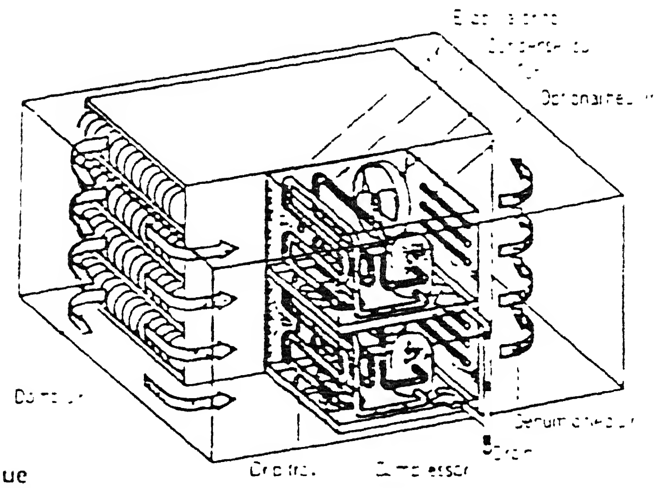


The technique.

The air knife uses high velocity low pressure air to blow water off the surface of a wide range of materials

EXHIBIT-13

TECHNIQUE - HEAT PUMP DEHUMIDIFIER



The technique

Heat pump dehumidifiers condense the moisture extracted from materials while recovering both the latent and sensible heat

EXHIBIT - 14

TECHNIQUE - INFRA-RED ENERGY

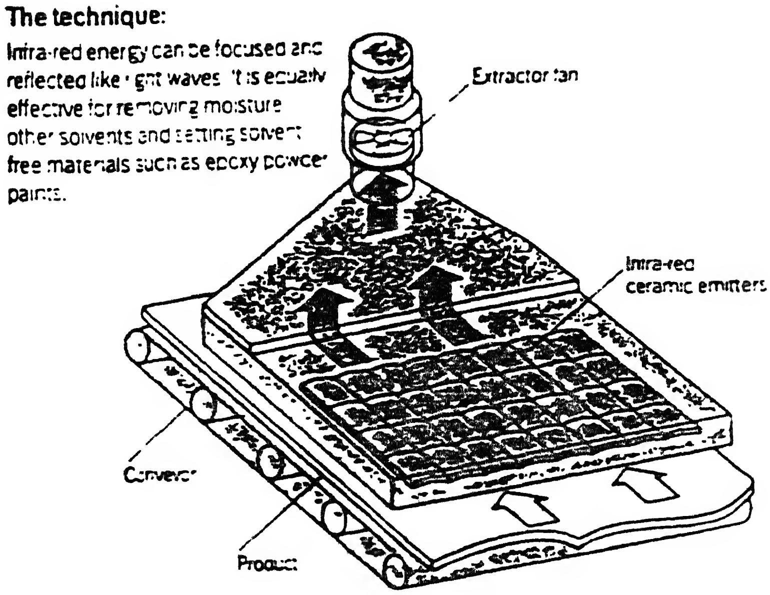


EXHIBIT - 15

TECHNIQUE : DI-ELECTRIC HEATING

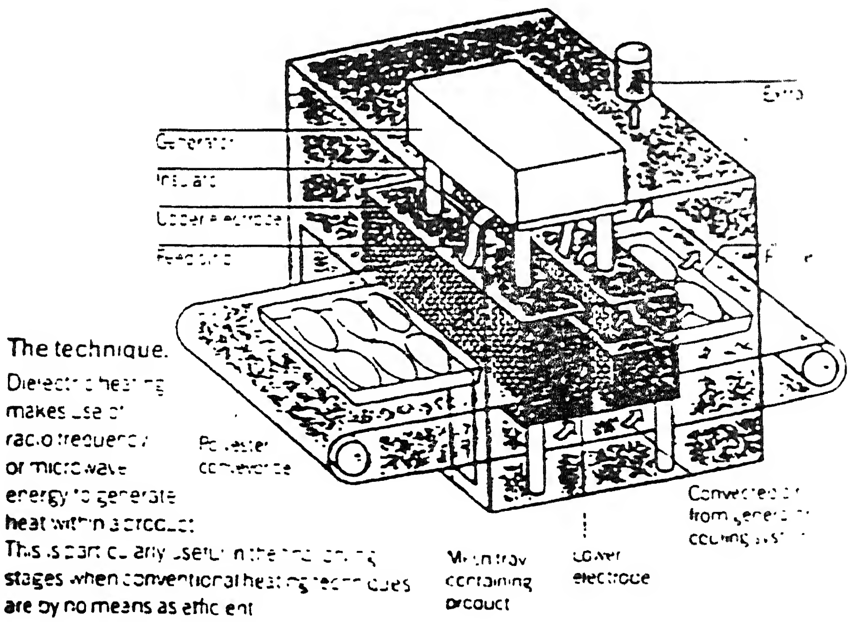
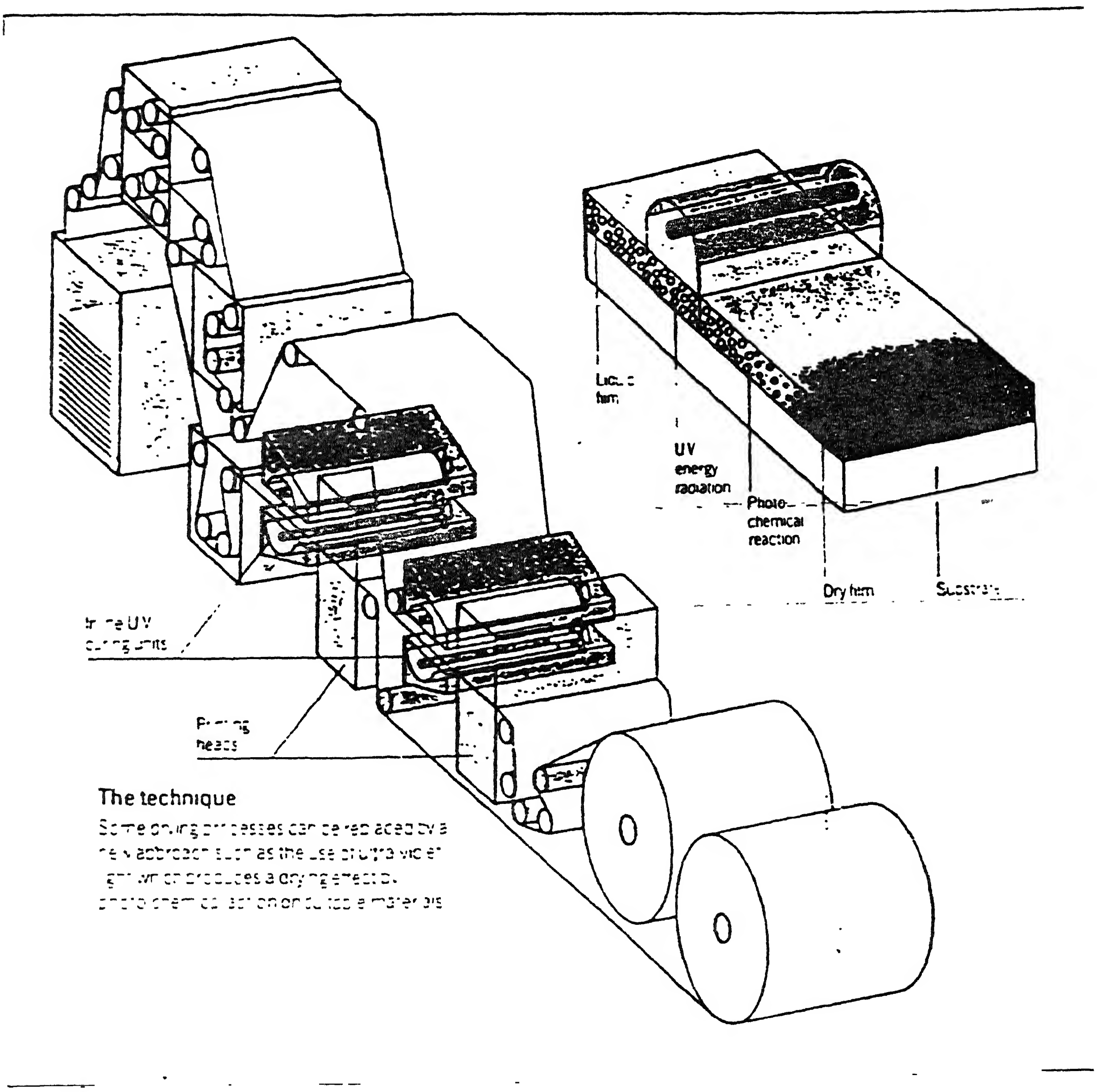


EXHIBIT 16

ULTRA-VIOLET DRYING



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2. *Energy User's Data Book* — edited by H.B. Locke published by Graham and Trotman Ltd
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   — McGraw Hill edition

PART – 2
EVAPORATION

PART – 2

ENERGY CONSERVATION IN EVAPORATION

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1.0 GENERAL

Evaporation can be defined as any process involving the vapourisation of a solvent or liquid dispersant which results in a more concentrated solution as product. Evaporation is used most frequently in the chemical, food and drink industries and in the production of desalinated water. Water is by far the most common material evaporated, although organic solvents are evaporated in a number of chemical processes.

2.0 BRIEF EQUIPMENT DESCRIPTION

The simplest evaporator (with the exception of solar ponds) in broad industrial use is the single effect evaporator A schematic representation is given in exhibit 1 The dilute feed is heated to its boiling point by steam in a heat exchanger. Partial vaporisation of the dilute feed occurs. The liquid/vapour feed mixture passes into the evaporator drum where the liquid and vapour (normally steam) separate. The liquid, which is now concentrated in the non-volatile components, is partly re-cycled to the heat exchanger and partly withdrawn as product The vapour is withdrawn from the evaporator drum using a steam ejector (or vacuum pump) and condensed

The main types of steam heated tubular evaporators in use today are :

1 Short tube (Standard) evaporators

2 Long tube vertical evaporators

   a Forced circulation
   b Climbing film
   c Falling film

3 Agitated film evaporators

4 Multiple effect evaoporators

Evaporators are also available in different types and designs to suit special purposes Some of them are shown in exhibit - 2. The optimum design depends on the material being evaporated, feed concentration, feed and product viscosities the temperature sensitivity of the product and various other factors.

3.0 EVAPORATOR TERMINOLOGY

Terms pertaining to evaporators are listed below

a Evaporation

b. Evaporator capacity

c. Steam economy

d. Fouling

e. Boiling point elevation

f. Heat sensitivity

g. Foaming

Brief definitions are given in exhibit 3.

4.0 ENERGY AUDIT APPROACH

The approach followed is more or less same as the one discussed in dryer energy audit In general what to look and measure in evaporators is given below:

1. Evaporator flow sheet with material and energy balance to assess evaporator steam economy
2. Quantification of various heat losses such as:
   a) Convectional and radiational losses
   b) Sensible heat losses in product out
   c) Heat of vapourisation lost to cooling water
   d) Heat lost in steam condensate
   e) Sensible heat lost in usable sensible heat
   f) Energy loss in (pump) drive inefficiency
   g) Energy loss in leakage
   h) Energy loss in non combustilbes, etc.
3. Ways to minimise above losses either by following good house keeping measures or by heat recovery
4. Instrumentation, and effective control of evaporators
5. Measurements to be made
   a. Mass flow rate of feed and product
   b Mass flow rate of steam heating fluid
   c. Inlet, outlet temps of feed product, steam and condensate d Surface temperature
   e. Evaporating pressures and temperatures at different stages
   f Steam used in ejectors
   g. Cooling water temperature (inlet and outlet)
   h. Rate of pressure rise or air leakage in evaporator
6. Instruments to be used
   1. Flow meters (Steam, water and materials)
   2. Temperature indicator with immersion and surface probe

3. Vaccum and pressure gauge
4. Steam trap tester
5. Power analyser

5.0 POTENTIAL AREAS FOR ENERGY CONSERVATION

The options for upgrading existing evaporators fall within three general categories :

1 Low-investment improvements external to the evaporator : basically fine tuning of the existing hardware.

2 Moderate-investment changes such as improved heat recovery from condensates and product streams.

3 Large-investment changes such as installing additional effects or adding a vapour recompression preconcentration system.

5.1 Low Investment Opportunities

Some of the low investment 'operational ' improvements applicable to existing evaporators are as follows·

A *Venting rates*

Non-condensibles enter the system with the feed or by way of system leaks. The main additional source of non condensable gases is dissolved air or other gases (usually CO2) entering vacuum system in a continuous liquid or vapour system. Cooling water normally contains 10 - 20 g/m3 of air dissolved. Boiler feed water has to be treated properly for dissolved oxygen, otherwise non condensible levels in the steam consumption will go up, which will in turn increase the steam consumption in the ejector because of high evacuation load. In multi-effect evaporators, the non-condensible vapour from the vapour space of one effect collect in the steam chest of the following effect These non- condensibles must be vented to prevent an increase in pressure and to maintain good heat transfer. Because the non- condensibles are co-mingled with steam, any venting beyond that required to maintain heat transfer wastes steam. If venting rates are too low, additional fresh steam is required to overcome the rise in boiling points, the decrease in heat transfer, and the loss of sensible heat contribution to flashing. Different venting procedures are given in exhibit 4.

If venting is too high, the steam is lost to the atmosphere or condenser Excess venting losses can be minimised by modifying the conventional venting method recovering the steam in each following effect and accomplishes all venting from the last effect.

B. *Air leakage*

Air leakage raised the level of non-condensibles in the vapour and therefore (except for the last effect) requires an increase in venting rates to maintain the correct temperature and pressure profile. The result is the same as that of excessive venting Excessive air leaks can also overload the vacuum jets and increase the pressures throughout the evaporator system

Air leakage may occur through flanges, inspection glasses cocks, valves, stuffing boxes, barometric legs, etc. The air leakge rates to be expected according to the volume of plant under vacuum and the quality of the vacuum seal connections are given in exhibit 5.

For evaporators which are working under vacuum, it is a necessary step to estimate the amount of air leaking in to it A simple and practical method is based on an estimation or measurement of the rate of pressure rise when a system is evacuated and isolated The acceptable value for leakage is given:

	Operating Pressure	Pressure rise rate m bar/min		
		Normal	Better	Best
<	0.013	0.6	0.3	0 07
	0.013 – 0.04	1.3	0.7	0.07
	0.04 – 0.13	2.6	0.7	0.07

C. *Fouling*

Fouling of either the process or the condensing vapour side of the heat transfer surfaces of the evaporator decreases heat transfer Reduced heat transfer rates cause loss of capacity, unless the steam pressure to the first effect is raised. If the operator follows this common practice to bring the evaporator back to capacity, the increased steam pressure then causes a loss in energy efficiency because of inreased condensate and product heat losses. Therefore, unless heat recovery equipment is used, the fouling cycle of an evaporator system between cleanouts can affect the amount of energy used The last days of operation before evaporator cleanout are less energy efficient Increasing the frequency of cleaning may show favourable economics.

D. *Optimum pressure profile*

Continual operation at pressure higher than those for which the system was designed should be prevented because the higher pressure profile results in higher energy requirements unless there is extensive heat recovery.

E *Water leakage*

Any water that leaks into the process dilutes the product and increases the amount of water to be evaporated. Possible sources of leakages are corroded heat exchange surfaces, pump seal flushes, and leaks in the valves providing water for cleaning out the evaporator during start-up and shut-down surprising amounts of water can be leaked into a high vacuum evaporator from these sources Presence of steam side leakage can be checked by checking the pH values or contamination levels of steam condensate before and after steam chest.

F. *Separator efficiencies*

If the vapour/liquid separation efficiency is poor, product will be carried over into the condensate of the following effect. The product yield is then reduced, and the pollution load is increased. The reduction in yield wastes all the energy expended to produce the lost product and increases the raw material costs When scaling materials, such as tars, salts, or oils, are entrained, fouling of the heat transfer surface of the next effect is accelerated Plugging of the demister pads in the separator can occur, which will adversely affect the pressure profile.

G *Radiation and convection losses*

The economics of adding additional insulation to an evaporator system depends directly on the temperature of each effect and the location of the unit. The amount of additional insulation that can be justified is estimated using the heat loss calculations in the Heat Transfer Manual and the economic analysis techniques in the

Economics Manual. Damaged, wet, or non-existent insulation is more often a greater source of loss than is inadequate thickness because most evaporator bodies operate at relatively low temperatures. Energy savings in reducing radiation and convection losses are dealt in Case Study 1

H. Condensor cooling water

In multiple effect evaporator, condensation of flash steam vapour occurs, the temperature of the cooling water will rise, thus also increasing the compression ratio and steam consumption. High cooling water rates, low cooling water feed temperatures and multistage condensation will all reduce the condensation temperatures and vapour pressures, and consequently the unit steam consumption. Contribution of noncondensables by cooling water in direct contact (jet type) condenser is given as:

Non condensible quantity (Kg/hr)

$$= \frac{\text{Cooling water (m3/min)} \times 100}{1\ 8 \times \text{inlet temp.}^{o}\text{K} - 400^{o}\text{R}}$$

5.2 Improvements Requiring Moderate Investment

Several further options for improving the energy efficiency of existing evaporators fall short of requiring major investment The most important of these moderate-investment improvements are:

A. *Improved heat recovery*

An evaporation system normally loses some energy through the hot concentrated product, condensates from the evaporator steam chests, final effect vapour, and steam jet exhaust

streams Increases in energy costs have greatly changed the economics of installing hardware to recover a portion of these losses. The decision on whether to use heat recovery is normally based on a straightforward balancing of energy cost savings versus the capital and increased pumping costs associated with the heat exchange equipment

When the feed is cold, it is usually the most attractive stream for recovering the low availability heat leaving the evaporator Depending on its initial temperature, the feed stream can often be pre-heated by the product and/or the condensate from the intermediate effects In all cases, the heat recovered directly replaces steam. This technique is limited eventually by the decreasing temperature difference between the receiving stream and the low availability energy supplier Heat recovery from steam condensate to preheat evaporator feed is illustrated in Case Study - 2

The required heat transfer area eventually becomes so great that further recovery is uneconomical. The ability to make full use of the heat in the condensates and product is a strong function of the existing feed temperature and its properties

B. *Condensate and product flashing*

The condensed steam from the steam chest of the first few effects of an evaporator still has available energy This energy can be recovered by exchange with the feed or another, cooler steam. If there is no low temperature stream available, then it may be economical to generate steam by flashing higher pressure condensate to the lower pressure in following effects

C. *Replacing Steam Ejector with Vacuum Pumps*

Steam driven ejectors for vacuum production and vapour compression are thermodynamically less efficient than mechanical compressors. After an ejector system has been designed and installed, it is possible to achieve maximum efficiency only by varying the steam supply pressure to the jet or less readily by changing the jet nozzle size. In some cases mechancial vacuum pumps need more maintenance than ejectors. Energy saving in this is given in case study - 3.

D. *Instrumentation and control*

An evaporator system must be instrumented adequately to provide the data necessary for evaluating system performance and to provide indicators for identifying problems affecting energy efficiency.

The economics of good instrumentation and control are difficult to document because the savings are always linked to other improvements. To evaluate and realise the savings of other improvements as discussed requires instrumentation and control at a minimum number of points. Pressure temperature and flow indicators must be used for measurements of the effect of steam rate and pressures of evaporator vapour lines. Controllers allow the operator time to maintain optimum process conditions. The data allows the operator time to maintain optimum process conditions. The data obtained allows the detailed evaluations required to plan future improvement.

All the foregoing modifications involve changes in the evaporator auxiliary equipment, maintenance of original design conditions or both. If several fold reductions in steam consumption ar desired, more extensive changes must be made.

5.3. Large Investments

The options available for radically reducing steam consumption involve either recompressing the overhead vapours for re-use or using these vapours in additional effects. Often, a combination of the two approaches is desirable. Although the capital investment required for these changes is large, the energy savings ar also extensive. In addition, both vapour recompression and additional effects can be used to increase capacity as well as save energy.

The main cause of energy wastage is that the latent heat contained in the evaporated vapour is lost from the system completely as low level heat in the condenser A number of designs are available which enable at least a part of the evaporated vapour to be reused to evaporate more vapour from the feedstock The leading energy efficient designs are·

1. Multiple effect evaporators
2. Thermal recompression evaporators
3. Mechanical vapour recompression evaporators

All the above designs save significant amounts of nergy but at the expense of higher investment Careful economic analysis is required, therefore , in selecting the optimum design for a new evaporator or in modifying an existing design. Basic configurations of above designs are illustrated in exhibit 6 & 7

Multiple effect evaporators are widely used (eg., in the dairy industry) Energy savings increase as the number of effects (or stages) increase. The energy savings that can be achieved by adding effects can be estimated using the following formula .

$$\% \text{ Energy savings} = \left[1 - \frac{N}{(N+n)} \right] 100$$

Where N = original number of effects

n = number of effects added

Benefits of using multiple effect evaporator over single effect evaporator is explained in Case Study 4.

The energy savings available from thermal recompression and mechancial vapour recompression designs need to be examined on a case by case basis However, in certain favourable applications, for example, mechanical vapour recompression designs consume as little as 10% of the energy required by a sinngle effect evaporator performing the same separation Case study 5 explains the improvement in steam economy in reusing a part of evaporated vapours as heating medium by thermocompression technique.

CASE STUDY 1

HEAT LOSS THROUGH EVAPORATOR SURFACE

INDUSTRY : Synthetic fibre

EQUIPMENT: 3 stage evaporator

FUNCTION : Concentrate spent chemical solution which is to be fed to crystaliser for further processing

FINDINGS

- Evaporator surface was poorly insulated
- Surface temperatures were high
- Poor maitenance

DATA

Ambient air temperature	=	35°C
Evaporator average surface temperature	=	60°C
Evaporator total surface area	=	150 m2
Evaporator operating hrs/year	=	7000 hrs
Heat lost through evaporation surface	=	150 Watts/m2

RECOMMENDATIONS

- Relay the insulation with a fibre glass wool in order to reduce the surface temperature slightly (10°C) higher than the room temperature

Energy savings	=	15 4 KL of oil/year
Cost savings	=	Rs 77,000/Year
Cost of implementation	=	Rs 1,00,000
Payback period	=	1 3 Years

CASE STUDY - 2

HEAT RECOVERY FROM STEAM CONDENSATE

INDUSTRY : Chemical

EQUIPMENT · Single effect evaporator

FUNCTION Evaporating organic collids in water from 10% to 50% solids content

FINDINGS :

It was situated away from the boiler house and no recovery of steam condensate to boiler house was done. Cold feed was used

DATA

Steam consumption	=	19,800 kgs/hr
Steam pressure	=	1 atm
Boiling point of solution in the evaporator	=	51 7°C
Evaporator pressure	=	102 mm of Hg absolute
Feed rate	=	24950 Kgs/hr
Feed entering temperature	=	30°C
Steam condesnate temperature	=	90 - 100 °C
No of operating hrs	=	3000 hrs/annum
Proposed feed inlet temperature	=	50°C
Steam saved	=	850 Kgs/hr

RECOMMENDATIONS

Install a heat exchanger to preheat feed up to 50 °C using steam condensate available at 90 - 100°C

Energy saved	=	183.6 KL of oil/Year
Cost saved	=	Rs 9 18 lakhs/year
Cost of implementation	=	Rs 2,00,000
Payback period	=	0 2 Years

CASE STUDY - 3

REPLACING STEAM EJECTORS WITH VACUUM PUMPS

INDUSTRY · Dairy

EQUIPMENT . Steam ejector

FUNCTION : To produce vacuum

FINDINGS

Steam jet ejectors were used to create vacuum and remove non condensate gases from the system It consumes more energy than conventional vacuum pumps

DATA

Evaporator Capacity : 5000 lit/hr

Steam consumption at ejector · 150 Kg/hr

Vacuum pump rating · 15 KW

Operating hrs per year = 3000 hrs

Operating cost of vacuum pump = Rs 54,000/Year

RECOMMENDATION

It was suggested to replace existing steam ejector with mechanical vacuum pump

Energy savings	=	16 2 KL of oil/Year
Cost savings	=	Rs 81,000/Year
Cost of implementation	=	Rs 1,00,000
Payback period	=	1.3 Years

CASE STUDY - 4

REPLACING SINGLE EFFECT EVAPORATOR WITH MULTI EFFECT EVAPORATOR

INDUSTRY : Dairy

EQUIPMENT : Milk Evaporator

FUNCTION : Milk concentration

FINDINGS

Single effect batch evaporator was used for evaporating milk Steam economy for single stage evaporators are low compared to multiple evaporators

DATA

Steam economy for single effect evaporator	=	1
Steam economy for 3 effect evaporator	=	4 0
Plant capacity	=	5000 lit/hr
Steam economy	=	Kg of water evaporated/ Kg of steam utilised

RECOMMENDATIONS

It was suggested to change over to a 3 stage evaporator with thermocompressor the steam economy of which is very good These type of units are functioning very well in other countries

Energy savings	=	800 KL of furnace oil/Year
Cost savings	=	Rs 40 lakhs per year
Cost of implementation	=	Rs 120 lkahs
Payback period	=	3 years

CASE STUDY - 5

ENERGY SAVINGS IN THERMOCOMPRESSION

INDUSTRY : Food processing

EQUIPMENT : Shell and tube climbing film evaporator

FUNCTION : Concentrate fruit juices

FINDINGS :

It was single state vacuum evaporator with no recycling of low pressure vapours Cold feed was administered to the evaporator. It was operating fifty percent of its rated capacity.

DATA

Present evaporation capacity	=	1000 kg/hr
Evaporator pressure	=	0 2 bar
Present steam consumption	=	1242 85 kg/hr
Driving steam pressure	=	5 bar
No. of working hrs per annum	=	5000 hrs

AFTER FIXING THERMOCOMPRESSION

Evaporator capacity	=	1000 kg/hr
Evaporator Pressure	=	0 2 bar
Driving steam pressure	=	5 0 bar
Recycled steam pressure	=	0 2 year
Quantity of steam recycled	=	330 Kg/hr
Total steam consumption	=	823.8 Kg/hr
Net reduction in steam consumption	=	420 0 kgs/hr
Improvement in steam economy	=	1 2138 - 0 8046
	=	0 4093 Kg/Kg of stea,
Fuel cost (approximate)	=	Rs 360/Ton of steam

NOTE

As the ΔT available for heat transfer falls from 91.7°C to 45°C, it needs double the amount of heat transfer area Since it is being operated at 50% of its capacity, heat transfer area is adequate to meet the existing production rate Preheated feed is, recommended

RECOMMENDATION

It is recommended to install a vapour compression system with heat exchanger for preheating the feed

Energy savings	=	151.2 KL of oil/year
Cost savings	=	7.56 lakhs/year
Cost of implementation	=	5.0 lakhs/year
Payback period	=	0.7 years

EXHIBIT I

SINGLE EFFECT EVAPORATOR

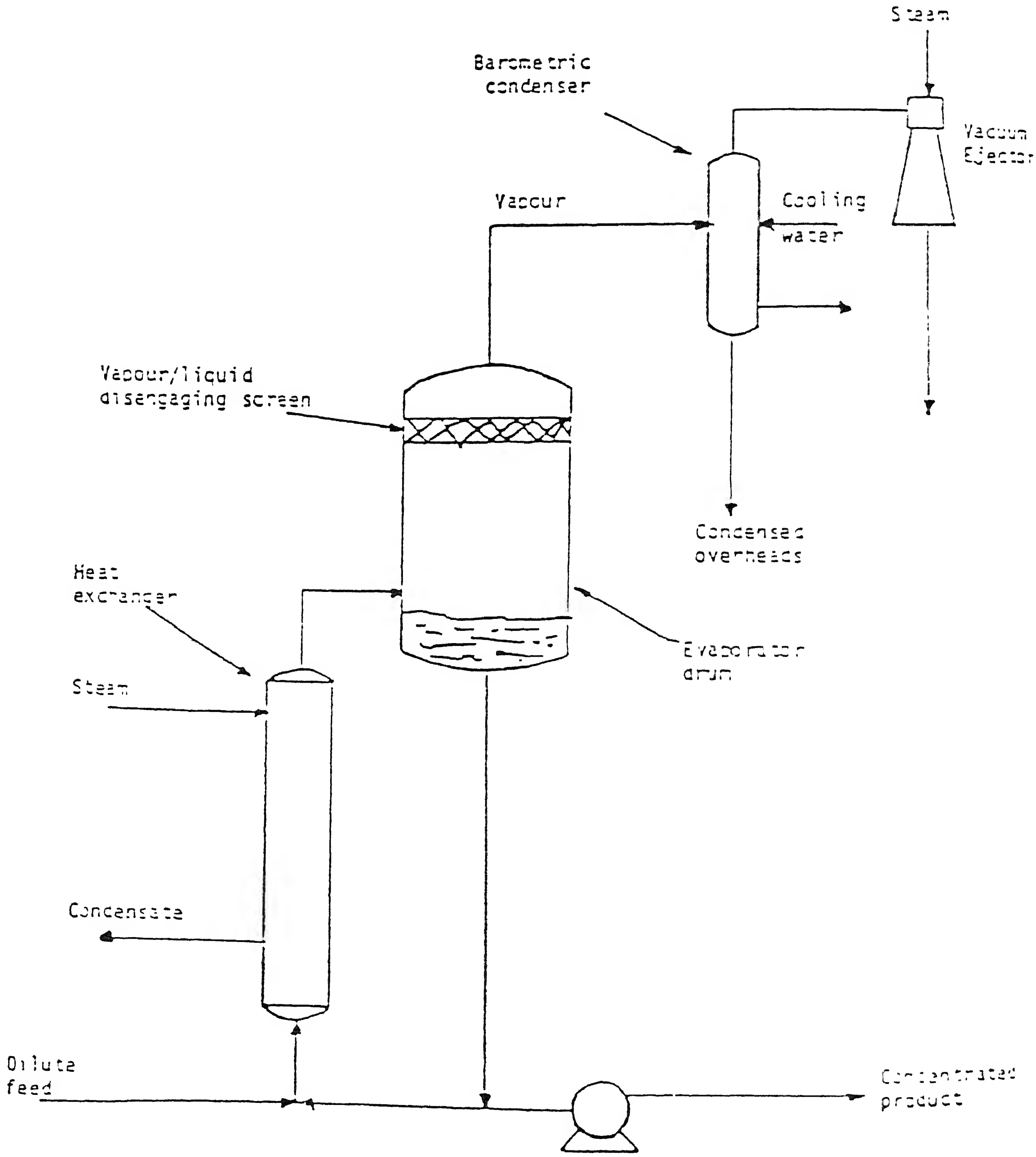


EXHIBIT 2

ALTERNATIVE EVAPORATOR CONFIGURATIONS

1. STEAM. 2. CONDENSATE. 3. VAPOUR. 4. FEED. 5. PRODUCT

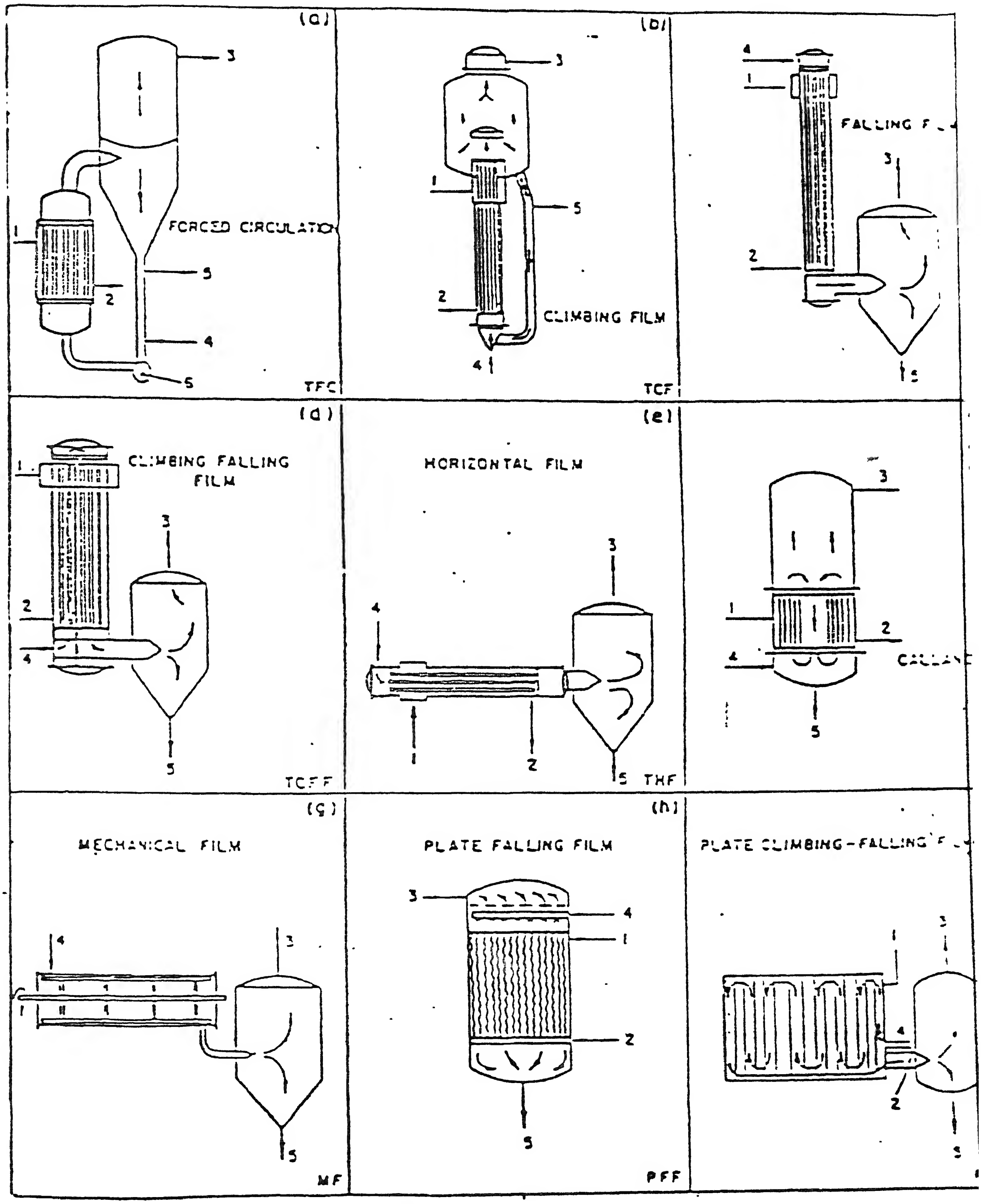


EXHIBIT 3
EVAPORATOR TERMINOLOGY

1. Evaporation :

Is the vapourisation of a solvent or liquid dispersant from a solution

2. Evaporator capacity :

Is defined as the number of kgs of water vapourised per hour

3. Steam Economy :

Is the number of kilograms of solvent vapourised per kilogram of steam

4. Fouling :

Is the reduction in overall heat transfer coefficient due to scale (deposit) formation in the evaporator tubes

5. Boiling point elevation :

At a given pressure, the boiling point of the solutions is higher than that of pure water. The increase in boiling point over that of water is known as the boiling plant elevation of the solution

6. Heat Sensivity :

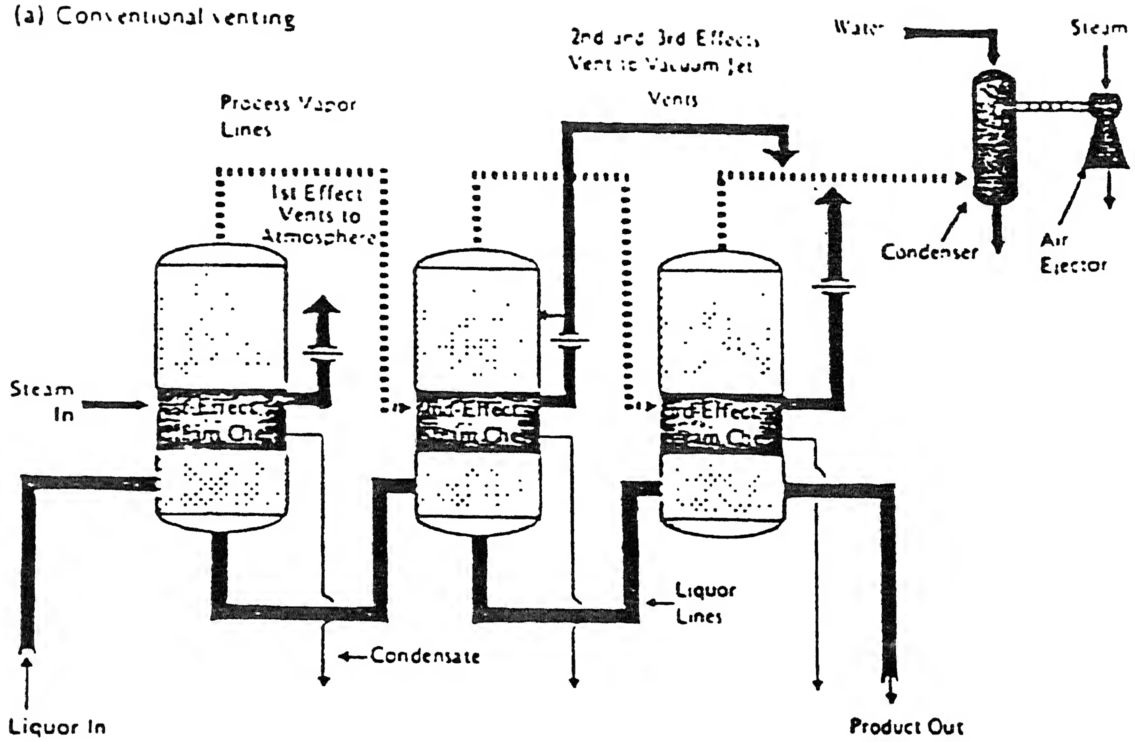
Many fine chemicals , food products and pharmaceuticals products are damaged or denatured when heated to moderate temperatures for relatively short times

7. Foaming :

Some materials, especially organic substances such as milk, foam during evaporisation. A stable foam accompanies the vapour out of the evaporator, causing heavy entrainment

VENTING SYSTEMS

(a) Conventional venting



(b) Series venting protects against excess venting.

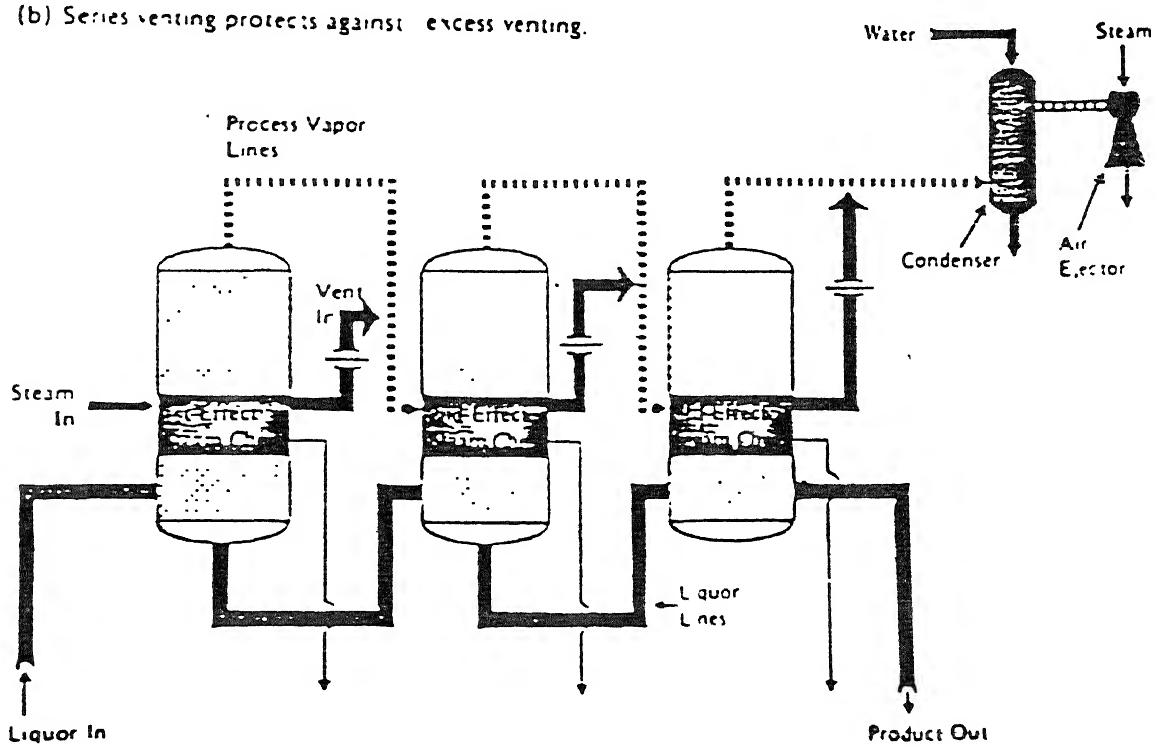


EXHIBIT - 5

TYPICAL AIR LEAKAGE RATES FOR VACUUM PLANTS

Volume under vacuum (m3)	Air leakage rate (Kg/hr)
0.2	0.2 - 0.5
1	0.5 - 1
3	1 - 2
5	2 - 4
10	3 - 6
25	4 - 8
50	6 - 12
100	9 - 18
200	12 - 25
500	30 - 60

EXHIBIT 6

SOURCES OF ENERGY AND PROCESS FLOWS IN THE TYPICAL MULTI-EFFECT EVAPORATOR

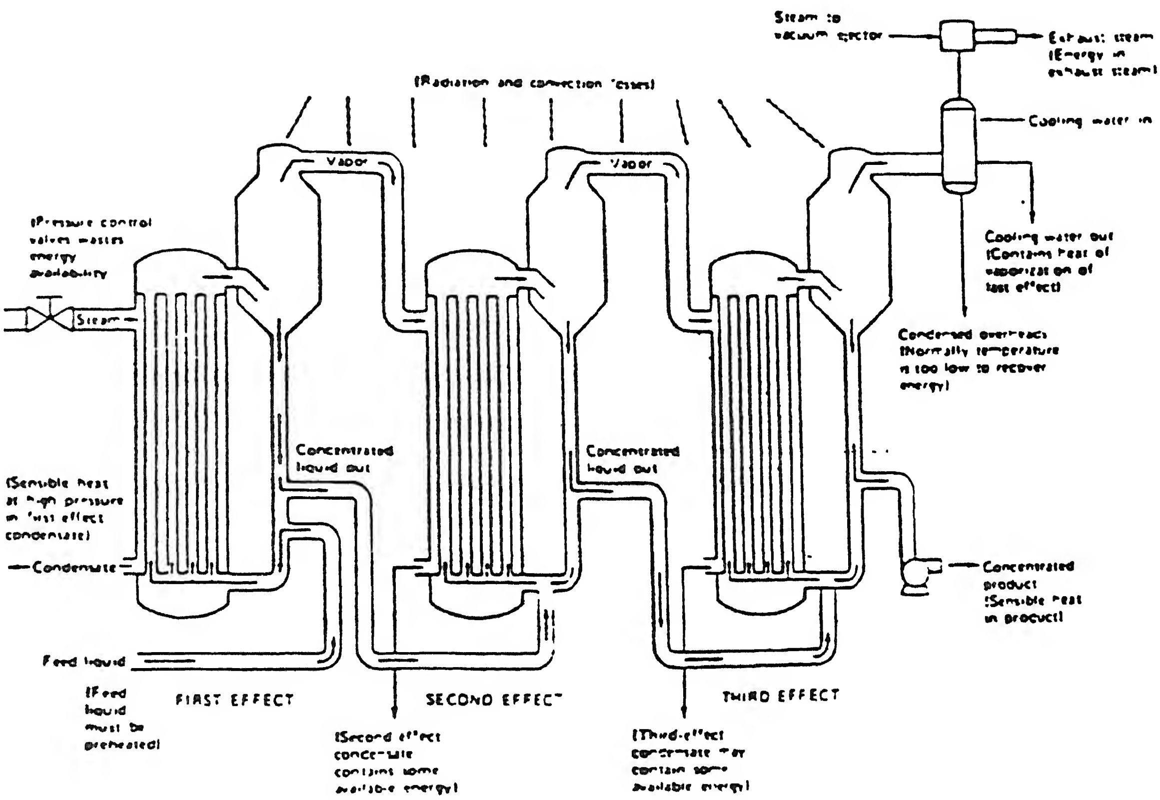
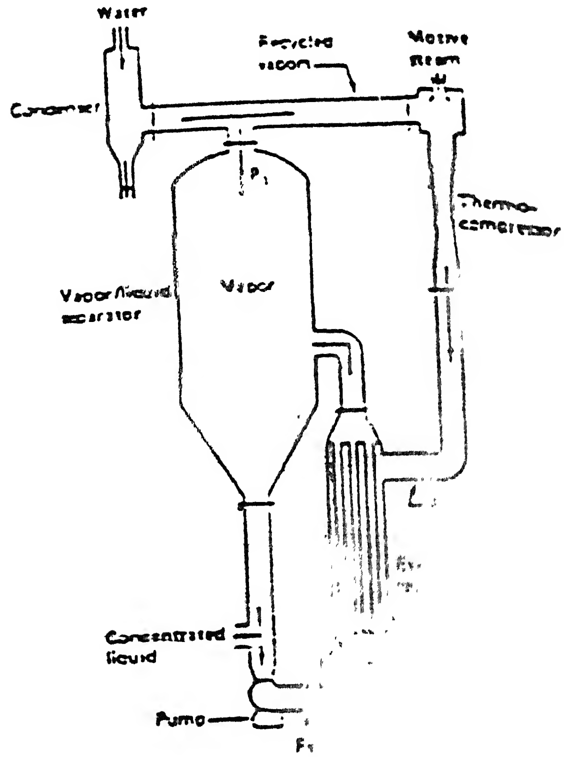


EXHIBIT 7

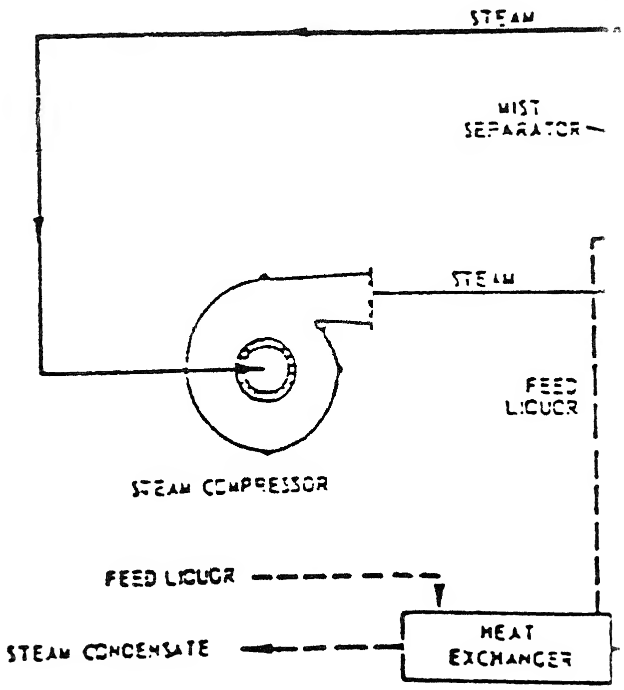
THERMAL RECOMPRESSION EVAPORATOR



EXHIB

Typical Mechanical

Eva



REFERENCES

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edited by P.m Goodall - Published by Westbury House

3.0 Process Heat Exchange - Chemical Engineering Magazine

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5.0 The Business Man's Energy Saver - by Niles